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Peripheral Vision Sensitivity With Night Vision Devices

By

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Aircrew Health and Performance Division

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Fort Rucker, Alabama 36362-0577

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Peripheral retinal sensitivities were measured for right and left eyes using a monocular night vision device (NVD)(single tube AN/AVS-6 Aviator's Night Vision Imaging System) in front of the right eye under simulated high and low night illuminations. Small circular targets were projected with a modified Goldman perimeter for six subjects. The color of the targets were white, green, and red. Targets were presented in the temporal field along the horizontal meridian at 10, 30, and 45 degrees to the unaided left eye, and at 30, 45, and 60 degrees for the NVD viewing eye. The results showed a decrease in sensitivity for the peripheral retina with the NVD and no effect on the nondisplay viewing eye, including the targets that were located within the projected field of view of the display eye (10-degree point). The nondisplay viewing eye (left) remained dark adapted to either the high or low night light level. Changes in the detection of green and white colored targets with peripheral vision by the display eye showed more effect in decreased retinal sensitivity than the red targets. However, the decreases in dark adaptation from viewing the display were similar to the differences in retinal sensitivity between the two simulated night illuminations for the nondisplay viewing eye.

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Background

The current image intensifier night vision device (NVD) used for night flight by the U.S. Army is the Aviator Night Vision Imaging System (ANVIS). The field of view (FOV) of the night vision goggle (NVG) is a circular 40 degrees. Light energy in the 600 to 900 nanometer wavelength range is amplified into visible light approximately 3000 times at and below ambient illumination levels of approximately 1/4 moon. The coherent electronic signals are then seen as a green image on the phosphor screen used in the ANVIS. The intensity of the image produced by the ANVIS is limited by an electronic automatic brightness control (ABC) to an average of approximately 1 to 2 foot-lamberts (fL) under high (> 1/4 moon) night illumination conditions.

A major concern with night vision devices is their restrictive FOVs with the possible increased potential for mid-air collisions. Accident data from 1980 to 1987 show that 47 percent (%) of NVG fatalities occurred from mid-air collisions (Joyce, 1987). However, during the evaluation of the modified faceplate (MFP) NVG, several pilots reported avoiding potential mid-air collisions by using the unaided look-around visual capability provided by the MFP (McLean, 1982). Since almost all NVG flights are conducted in congested airspace on military installations at altitudes of less than 100 feet above ground (nap of the earth, low level, and contour flight), the risk factor for a mid-air collision with NVGs would seem to be much higher in these flight modes than in other type flying, especially since the aircraft are flown below radar detection altitudes and possible assistance from collision avoidance systems.

Many military pilots have stated their desire to use the ANVIS during night cross country flights at normal visual flight rules (VFR) altitudes. The primary advantages would be better ground resolution in case of an emergency landing and much greater aircraft detection ranges within the NVG FOV in marginal visibility. Civilian medical evacuation and Civil Air Patrol (CAP) pilots also have expressed interest in the use of NVGs at night to aid in determining the location of accident sites, suitable landing areas and to detect potential ground hazards during casualty extractions. The main concern with using the 40- degree FOV NVGs at VFR night altitudes is the potential failure to detect with peripheral vision other aircraft on a collision course that may normally be detected without NVGs.

Glick et.al., (1975) showed that when using NVGs, the eyes are neither fully light nor dark adapted. With the AN/PVS-5 NVG, the dark adaptation level measured immediately after removing the goggles in the parafoveal area was equivalent to approximately 10 minutes of dark adaption from a preadaptaion level of 662 fL for 2 minutes; full dark adaptation after removing the goggles was achieved 1.5 to 3 minutes later.

The color, size, and intensity of the adapting field also have been shown to affect dark adaptation recovery time to specific levels for targets of various sizes and resolution requirements (Cavonius and Hilz, 1970). However, these effects have not been examined for the peripheral retina.

The presence of an edge or border near a target will also effect target detection up to approximately 2 degrees from the edge (Aulhorn and Harms, 1972). For the standard 18-mm eyepiece ANVIS and viewing at the maximum 20-mm eye clearance distance to obtain a full 40-degree FOV, the eyepiece housing blocks approximately 8 degrees before the unaided FOV is available. Therefore, detection of targets at the edge of the unaided FOV could be decreased.

The helmet display unit (HDU) for the AH-64 Apache helicopter is monocular with a 30- by 40-degree FOV. The phosphor is P43, which is slightly more yellow-green than the green P20 and P22 phosphors used in Omnibus II and III purchased ANVIS. Apache pilots, during pilot night vision system (PNVS) training, must learn to switch awareness from the HDU viewing eye to the unaided eye for viewing either inside the cockpit or outside if the ambient illumination is sufficient. However, we do not know how well the unaided (nonviewing) eye can detect objects within or outside the HDU FOV. We also do not know how well the aided (display viewing) eye detects targets outside its display's FOV.

The next generation night imaging device for the ground soldier will be monocular (AN/PVS-14). Despite several field studies with binocular, biocular, and monocular night vision goggles, the differences and preferences between biocular and monocular devices have not been well quantified (CuQlock-Knopp et al., 1995). Different tasks and ambient illumination levels may favor one or the other device. The advantages or disadvantages of the unaided or nondisplay viewing eye for a monocular device have not been measured.

This study's primary aims were three-fold and attempted to quantify the following objectives based on the above discussion:

1. With a binocular or monocular night imaging system such as the ANVIS and the Apache HDU, what changes in peripheral retinal sensitivity (dark adaptation) occur outside of the display's 40-degree FOV of the viewing eye(s) under simulated ambient night lighting conditions?

2. With a monocular system, what changes in retinal sensitivity occur outside the apparent display's 40-degree FOV for the nonviewing eye?

3. For the nonviewing eye, what changes in retinal sensitivity occur within the apparent overlapped display's FOV of the viewing eye compared to the dark adapted eye without the display?

For each of the above three objectives, the color of the targets and the range of night background illuminations were additional qualifying variables. See figure 1 for schematic of target locations on the perimeter.

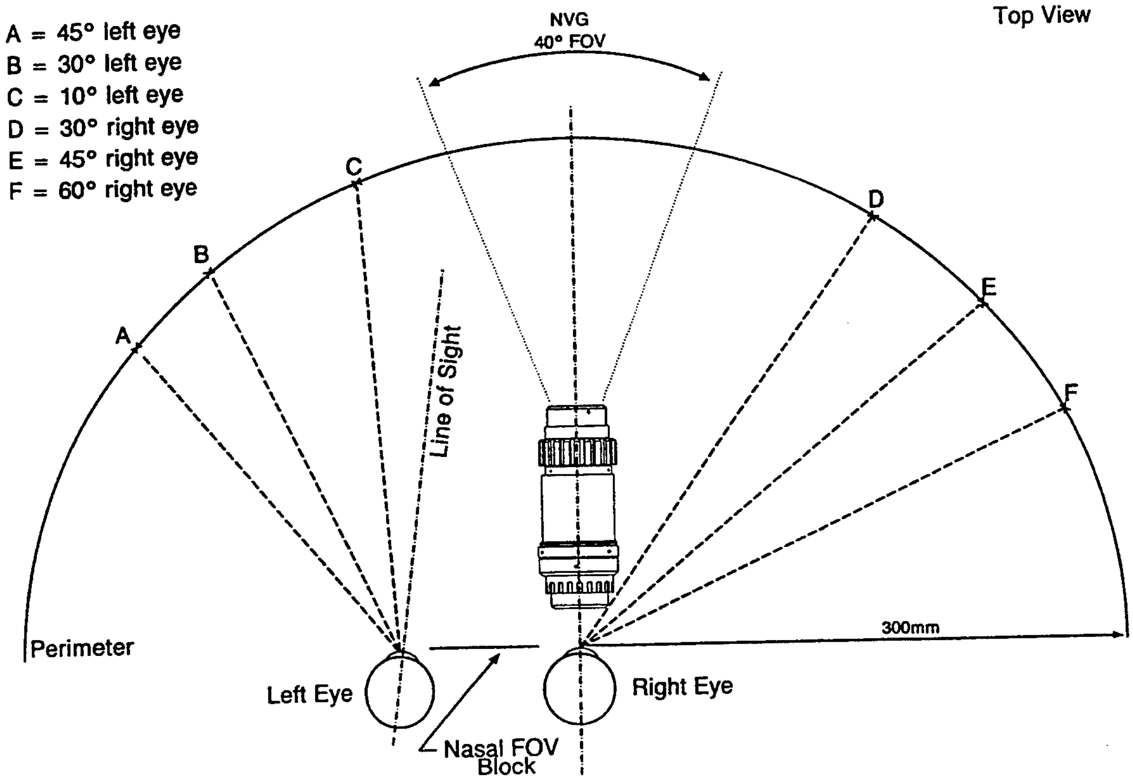

Figure 1. Schematic of target locations.

Since the apparent color of the phosphors used for both NVGs and the Apache HDU is greenish, the retinal sensitivity to different colored stimuli for the display viewing eye would be expected to change as a function of the intensity and color of the adapting field. That is, after viewing a green display, we would expect the average detection intensity of a green target to increase more than for a red target. The average detection intensity required for a white target would be expected to fall somewhere in between. These colors correspond to the colors of external lighting on aircraft: red, green, and white.

Military significance

1. Improved flight safety. If the study shows significant residual peripheral retinal sensitivity outside the 40-degree night image device FOV, this information could be used to request approval from the Federal Aviation Administration (FAA) to use night imaging devices during routine night cross country flights at all altitudes outside normal NVG approved airspace, at least for military aircraft. In an emergency such as an engine malfunction, the pilots with NVGs could evaluate suitable landing areas much better than pilots using only their unaided vision at night.

2. Improved knowledge of target detection with night imaging devices. Detection and resolution characteristics of night image devices have been modeled within the display's FOV (Stefanik, 1994), but not outside the display's FOV. For a monocular device, information on the sensitivity of the nonviewing eye is also unknown. The program managers for the infantry night imaging devices, such as the "Land Warrior Program," will be provided quantitative detection data to assist in selective trade-off studies among monocular, biocular, and binocular displays.

Methods

Subjects

Subjects were selected without regard to gender and met Class II flight visual requirements. These requirements include: resolution correctable to 20/20 in each eye, normal color vision, phorias, and stereopsis. In addition, the subjects were less than 35 years old with unaided near vision of 20/20 and no abnormal visual fields. Corrective spectacles were not permitted. For the six subjects used in this study, four were males and two were females with an age range from 25 to 32 years.

Procedures

Subjects were briefed on the study to include: purpose, duration, voluntary consent requirements, and subject rights including the right to withdraw at any time without adverse consequences (see Appendix A). The volunteers were screened using the Armed Forces Vision Tester for aided and unaided acuity, phorias, and stereopsis. Normal color vision was verified with pseudo-isochromatic plates. Objective refractive errors were measured with a Marco auto-refractor, and manifest subjective refractive errors with a phoropter by a research optometrist.

A modified Haag-Streit manual Goldman-type perimeter (Harrington & Drake, 1990) was used to measure retinal sensitivity in the horizontal meridian at different locations in the FOVs and under high and low simulated night ambient illuminations (Figure 2). The broad ring band red and green filters that accompanied the perimeter were used to change (filter) the color of the white target. The luminance of the targets and the two background luminances of the perimeter were measured and the background luminance adjusted with a 1980A Pritchard photometer using the photopic and scotopic filter settings on the photometer. Photopic luminance measurements of the backgrounds through the ANVIS eyepiece were also taken for reference.

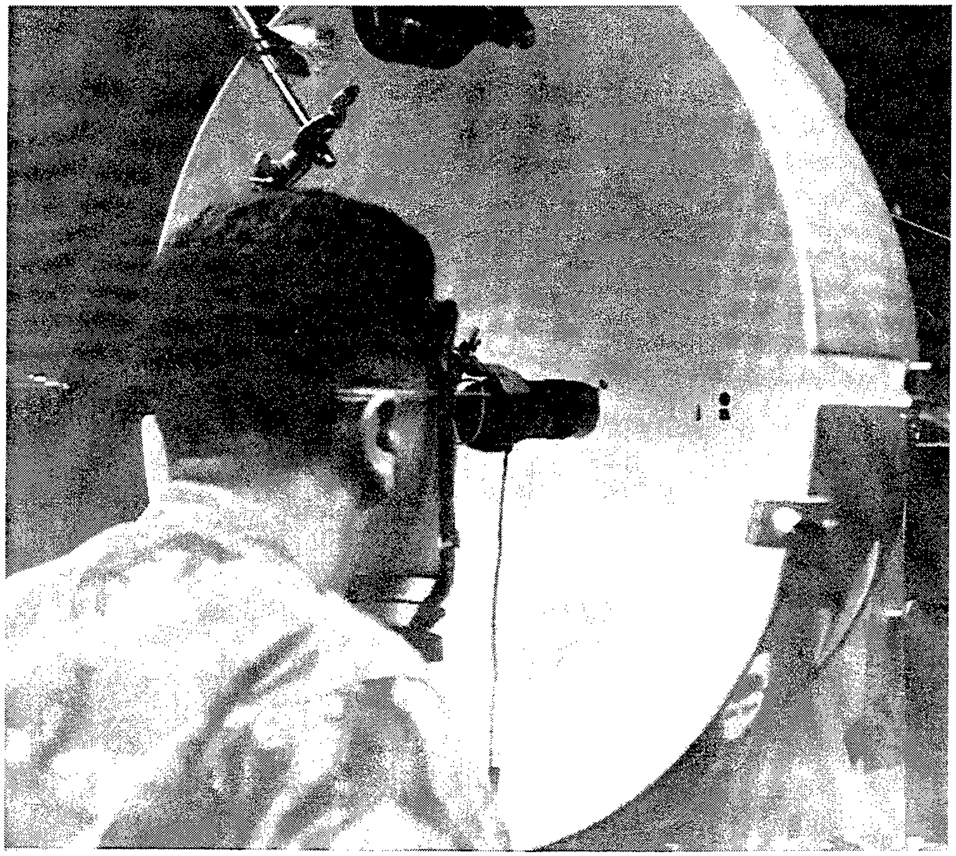

Figure 2. Goldman perimeter with single tube ANVIS.

A single 3rd generation (Gen III, Omnibus II) image intensifier channel (tube and optics), removed from an ANVIS (AN/AVS-6), was mounted in front of the subject's right eye. An auxiliary lens was added to the ANVIS objective lens to provide focus at the distance of approximately 15 centimeters. The eyepiece was focused at -0.50 diopters (2 meters) with the aid of an 8X dioptometer. The simulated night high background luminance value was determined by slowly increasing the background illumination of the perimeter until the ABC in the image intensifier was just activated. The lower light level for this study was the lowest available background luminance with the perimeter, with the addition of a partial mask over the perimeter illuminator. This low background level was estimated to be less than simulated starlight. To obtain a no display (NVG) background for the right eye, but retain the central fixation point without removing the single tube ANVIS, a small hole (approximately 1-mm diameter) was punched in the eyepiece lens cap and inserted on the eyepiece. Through the pin hole in the eyepiece lens cover, the subject could see the perimeter fixation points with the ANVIS, but with a reduced display intensity and an FOV of less than approximately 5 degrees to the eye.

To prevent the right or left eye from seeing the targets presented to the other eye in the temporal FOV, the subject wore a modified aviator metal frame spectacle with clear nonprescription lenses that obscured the nasal FOV. In the bridge area of the frame, black felt was taped creating a central obstruction of approximately 45 millimeters.

To accurately position the eye at the maximum viewing distance from the ANVIS eyepiece and still obtain the full 40-degree FOV, the subjects were taught the NVG sighting method using a NVG eyepiece simulator. At approximately 20 mm of eye clearance, the 40-degree FOVcan be obtained with central fixation. When the subject looks at the edges of the field of view at the 20-mm viewing distance, the subject could observe slight vignetting within the NVG FOV in the direction of gaze. At the beginning of a set for each colored target presentation, the unaided lateral FOV of the display eye was measured to verify that the viewing distance to the NVG was correct, and the 30-degree target location was not blocked by the ANVIS eyepiece.

The subjects were dark adapted for 30 minutes prior to data collection. During any given session, the selected background luminance of the perimeter was kept constant, changing only the color of the targets. The target size was either 1/4 mm^2 or 1 mm^2 with a duration of 1 second. The target intensity would begin at least 0.20 log neutral density (ND) steps below detection and increased in 0.10 log steps until detected. All three colors were used in a session. An attachment for static perimetry permitted accurate and repeatable placement of the target stimulus at the different FOV locations.

Stimuli presentation

Randomizing the presentation of all of the variables from the 54 stimuli combinations (3 background illuminations, 3 colors, and 6 positions) with 5 trials for each condition would be desirable, but not timely to the subjects because of the equipment limitations and time required for dark adaptation after different levels of ambient illumination. Instead, we balance the sequence of presentations for the variables among the six subjects for the three colors of the target and the three illumination conditions.

An electronic rhythm generator was used to produce drum beats at 1-second intervals to mask instrument sounds during stimuli presentation and to ensure a 1-second exposure for the manually controlled targets. The subject had to respond within 1 second after the presentation for a valid response. Subjects were told when an invalid response occurred both during the practice session and during the trials where the event was recorded.

The sequence for the six target locations for each session was determined with a random computer program. The intensity of the target was increased from nonseeing to seeing (ascending order) in 0.10 log units until detected. The subjects did not have to identify the color of the targets. After five trials at a given location, the target would be moved to the next scheduled position for another series of five trials. Between trials and during the relocation of the stimulus, the subjects were instructed to move their eyes throughout the NVG FOV as if searching for a target. Immediately prior to initiating and during a trial, the subjects were instructed to fixate through the NVG tube at a central fixation point in the perimeter.

Determining target locations for the
nondisplay viewing eye (left)

The perimeter is designed for monocular testing of the FOVs by positioning the eye being evaluated at the center of the perimeter curvature. The positions along the arch of the perimeter are calibrated in degrees relative to the designed eye position. When the perimeter is used binocularly, as in this case, the calibrated angular positions are not the same for the opposite eye that is not aligned at the center of curvature of the perimeter. Therefore, to place the targets at a given angular location to the nondisplay eye that was not located at the center of the radius of the perimeter, a calibration procedure was required for each individual at the beginning of each of the three sets in a session based on their eye separation and phoria determined with the perimeter.

Viewing the perimeter binocularly, the distances to the targets projected in the perimeter were also slightly shorter to the nondisplay eye, and therefore the targets presented to the nondisplay eye were slightly larger (approximately 11 to 16% increase in diameter) than the same targets presented to the display eye. A doubling of the target diameter (100%) equates to a decrease in the neutral density value by 0.50, according to the perimeter manufacturer (Harrington and Drake, 1990). Therefore, the 16% size increase would equate to approximately a 0.08 neutral density value decrease in sensitivity (0.16 x 0.50). The neutral density data for the 30-and 45-degree positions for the left eye were corrected for this size discrepancy.

At the beginning of a session (for a given background illuminance and target color), the angular alignment position of the nondisplay eye, relative to the display eye, was determined by having the subject align the projected circular target with a fixation mark on the perimeter that was seen at approximately 10 degrees nasally by the display viewing eye. The subjects were instructed to focus only on the fixation mark (very narrow triangle) as seen with the single tube ANVIS and not the target. Because of the geometry, the target seen by the nondisplay eye would not enter the FOV of the ANVIS when the two were aligned unless the subject had excessive esophoria at the simulated 2-meter accommodation viewing distance. This phoria alignment procedure was also repeated at the end of each set in a session to estimate eye drift.

Since the image seen with the right eye through the ANVIS could not be fused visually with the left unaided eye image, this phoria value determined from this procedure provided a good estimate of the actual retinal angular locations of the stimuli for the nondisplay eye (left). The other two peripheral target designations for the left nondisplay eye used in the study (30 and 45 degrees temporally) were then calculated on a programmable hand calculator using the viewing distance (300 mm), the interpupillary distance (IPD), and the measured phoria alignment value from the perimeter. Note that the 10-degree alignment point was the value from the phoria measurement at the beginning of a set.

Because the 10-degree temporal target to the nondisplay eye could approach the location of the blind spot of the eye, which is located approximately 15 degrees temporally from the fovea, a separate fixation point (small square) was positioned approximately 4 degrees (as seen by the

display eye) below the circular central fixation point. During the 10 degree target presentations only, the subjects were instructed to fixate on the lower square target during these trials. Otherwise, all fixations were directed to the central circular marker in the center of the perimeter.

Experimental Design

The independent variables were simulated night background illumination, target color, and peripheral vision location with and without the full FOV from the single tube NVG (Table 1). The minimum display image condition with the small restrictive aperture on the eyepiece of the ANVIS under the low background illumination is labeled and referred to as the *Low w/o NVG* throughout this report. The unaided left eye was exposed to two background levels of illuminations (high and low) and the right eye with the display was exposed to three different adapting background levels through the ANVIS (high, low, and low w/o NVG).

Table 1.
Independent variables.

Background Illumination	Target Color	Peripheral Location temporal field	
		Right eye	Left eye
High	white	*	10°
Low	red	30°	30°
Low w/o NVG	green	45°	45°
		60°	**

* 10 degrees not used for display eye (within NVG FOV)
** 60 degrees not used for left eye (equipment limits)

The dependent variable was threshold sensitivity as measured in 0.10 log ND filters for the equivalent 1 mm^2 size targets. For the readers not familiar with ND filter transmissions, conversions from log neutral density filter to percent (%) transmission are shown in table 2. Also for reference, the standard Army aviator sunglasses or tinted helmet visors have approximately 15% transmission (0.82 ND).

Table 2.
ND value conversion to percent transmission.

ND value	percent transmission	ND value	percent transmission
0.0	100%	**0.7**	20%
0.1	79%	**0.8**	16%
0.2	63%	**0.9**	13%
0.3	50%	**1.0**	10%
0.4	40%	**1.3**	5%
0.5	32%	**2.0**	1%
0.6	26%	**3.0**	0.1%

Five consecutive trials were conducted on each subject for each background illumination (3), target color (3), and retinal location (6). Six subjects completed all of the trials for a total of 1620 data points (5 x 3 x 3 x 6 x 6) for analysis.

Results

Photometric Measurements

High background photopic luminance in the perimeter was set just above the automatic brightness control (ABC) value of the single tube ANVIS at 3.70×10^{-4} fL (-3.432 log fL). The white unfiltered target luminance measured 73 fL (1.863 log fL). For photopic and scotopic measurements, the green filtered targets equated to 0.69 and 0.56 neutral density filter (ND), respectively, compared to the unfiltered white target. The photopic and scotopic measurements for the red filtered target equated to 1.62 and 5.37 ND, respectively. This large difference of 3.75 ND (5623 X) between photopic and scotopic sensitivity for the red target is due to Purkinje's shift. A quick spectral scan of the perimeter red filter showed a similar curve to the Kodak Wratten filter #92, but shifted slightly more towards the longer wavelengths with approximately 1 percent (2.0 ND) photopic transmission.

Measured physical difference between the *high* and *low* background conditions in the perimeter was 1.6 ND filter (39.8 X) for both photopic and scotopic measurements. Note that the background luminances in the perimeter were controlled with a variable aperture, which does not change the spectral composition of the light with changes in luminance. The background luminances (9.29×10^{-6} fL photopic) for the *low* and *low without* (w/o) NVG conditions were the same.

The photopic luminances measured through the ANVIS eyepiece were 1.37 fL for the high background and 0.037 fL for the low background settings. Since the ANVIS is basically a linear device for light amplification below the ABC level, and the high background luminance was set just above the ABC level, the ratio between the high and low background luminance values in the perimeter (39.8:1) was only slight greater than the ratio of the corresponding ANVIS luminous outputs (37:1).

Peripheral Retinal Sensitivity:

The mean retinal sensitivity at each retinal location for each of the three colored target are shown in figures 3 through 5 in separate plots for each background illumination. Figures 6 through 8 show the same data in separate plots for each target color at the different background illuminations. Indications of the variability of the data among subjects such as standard deviations (SD) or standard errors of the means (SEM) are not shown on these graphs to minimize congestion. The means, standard deviations, standard errors of the mean, and 95% confidence intervals were determined at each retinal location for each background level and target color (six subjects), and are listed in Appendix B.

The NVG FOVs in the figures are shown to aid in visualizing the relative target locations. The tops or values of the indicated NVG FOVs were arbitrarily set and are for graphic purposes only. The range of the neutral density scales (y axis) was kept constant for figures 3 through 8 to assist in estimating the differences between plots.

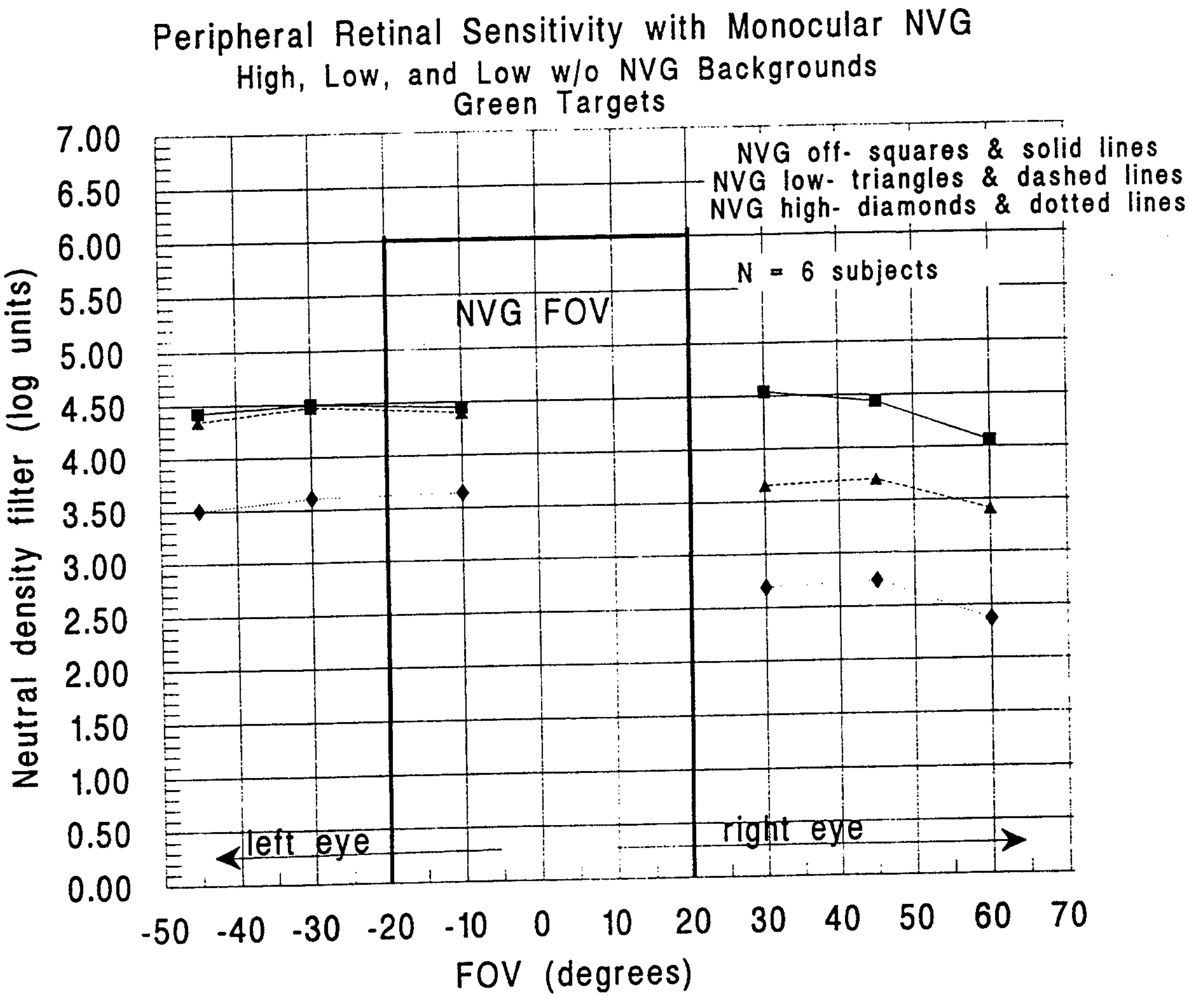

Figure 3. Green target detection effects.

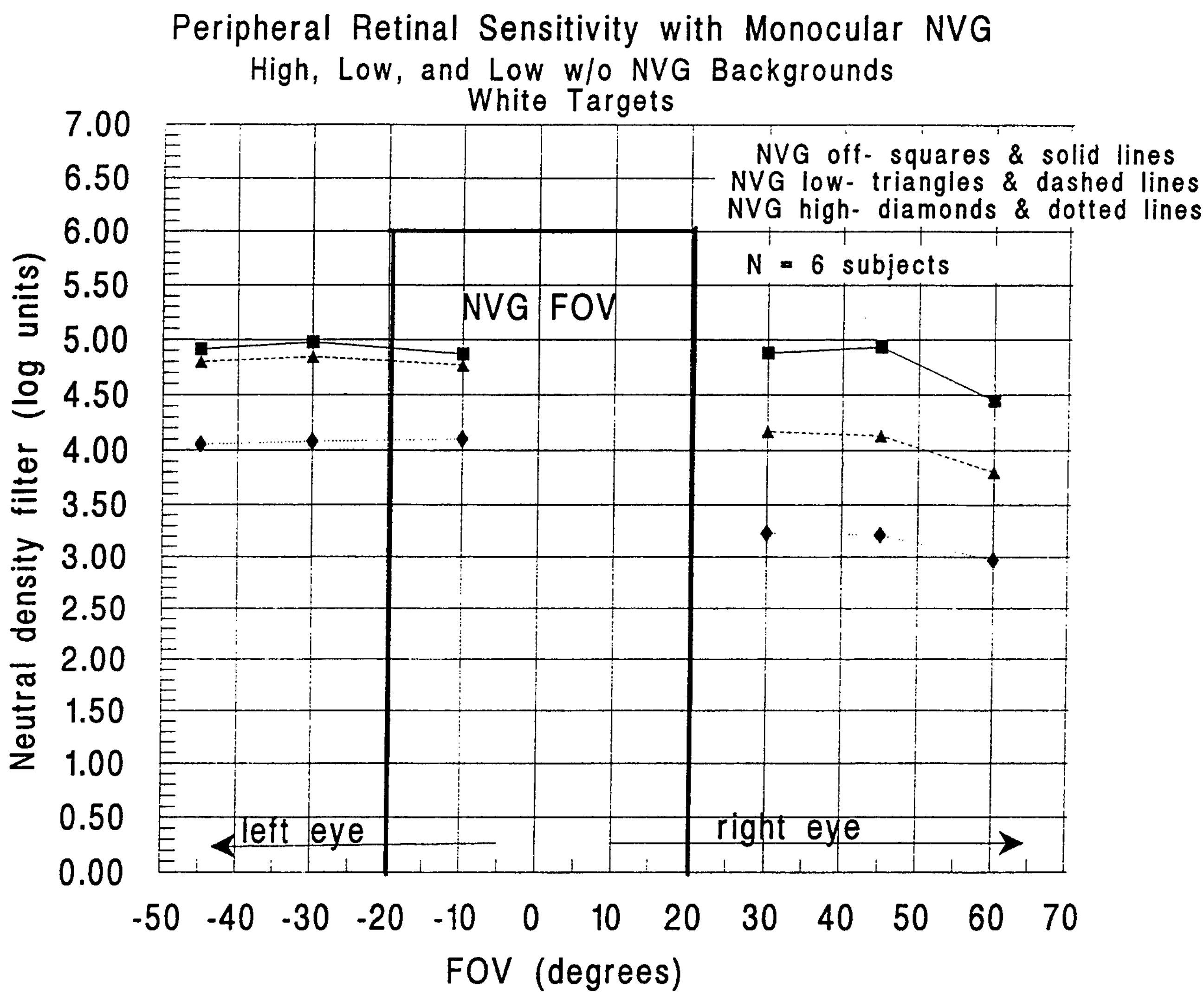

Figure 4. White target detection effects.

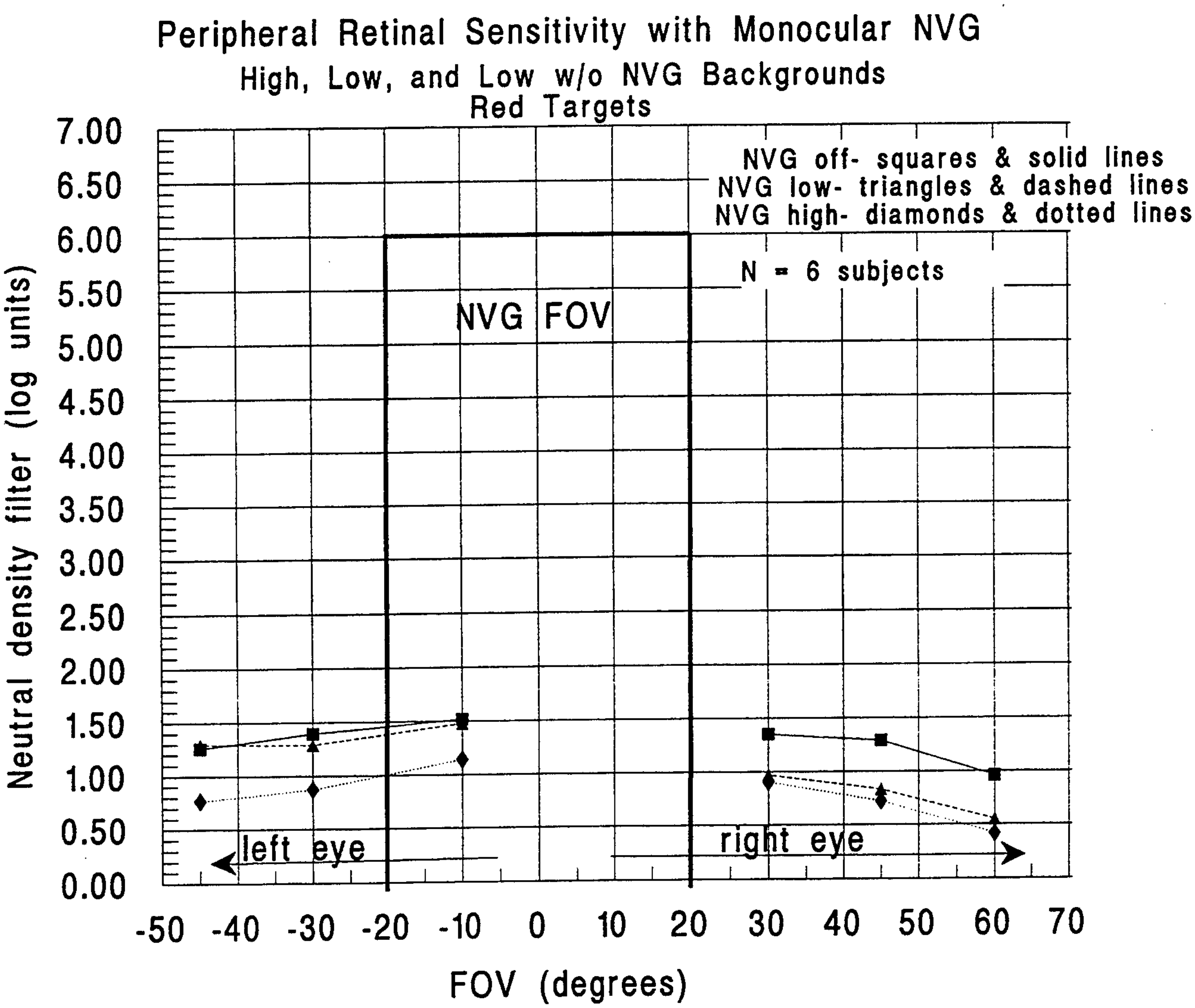

Figure 5. Red target detection effects.

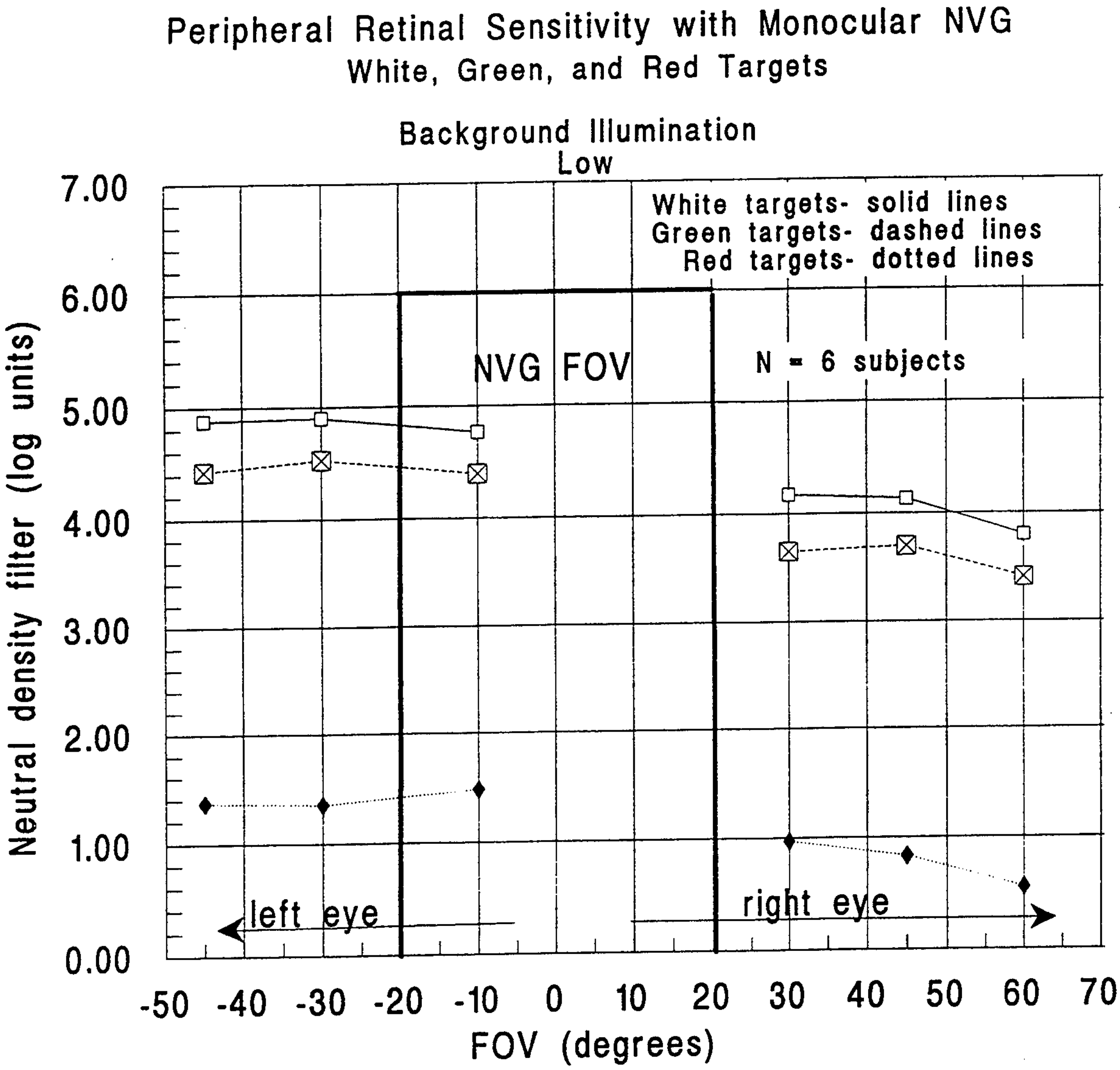

Figure 6. Background effects - illumination low.

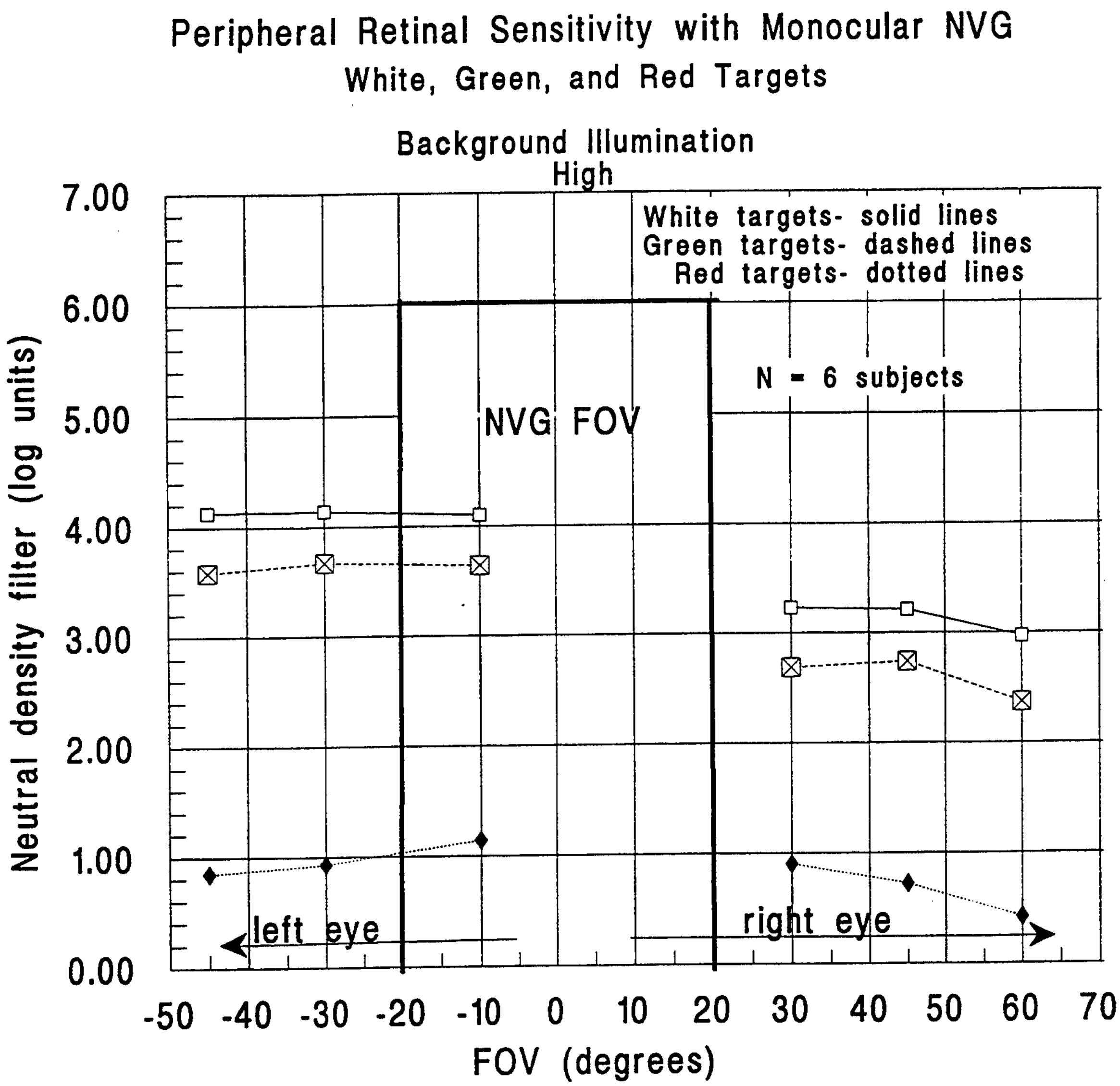

Figure 7. Background effects - illumination high.

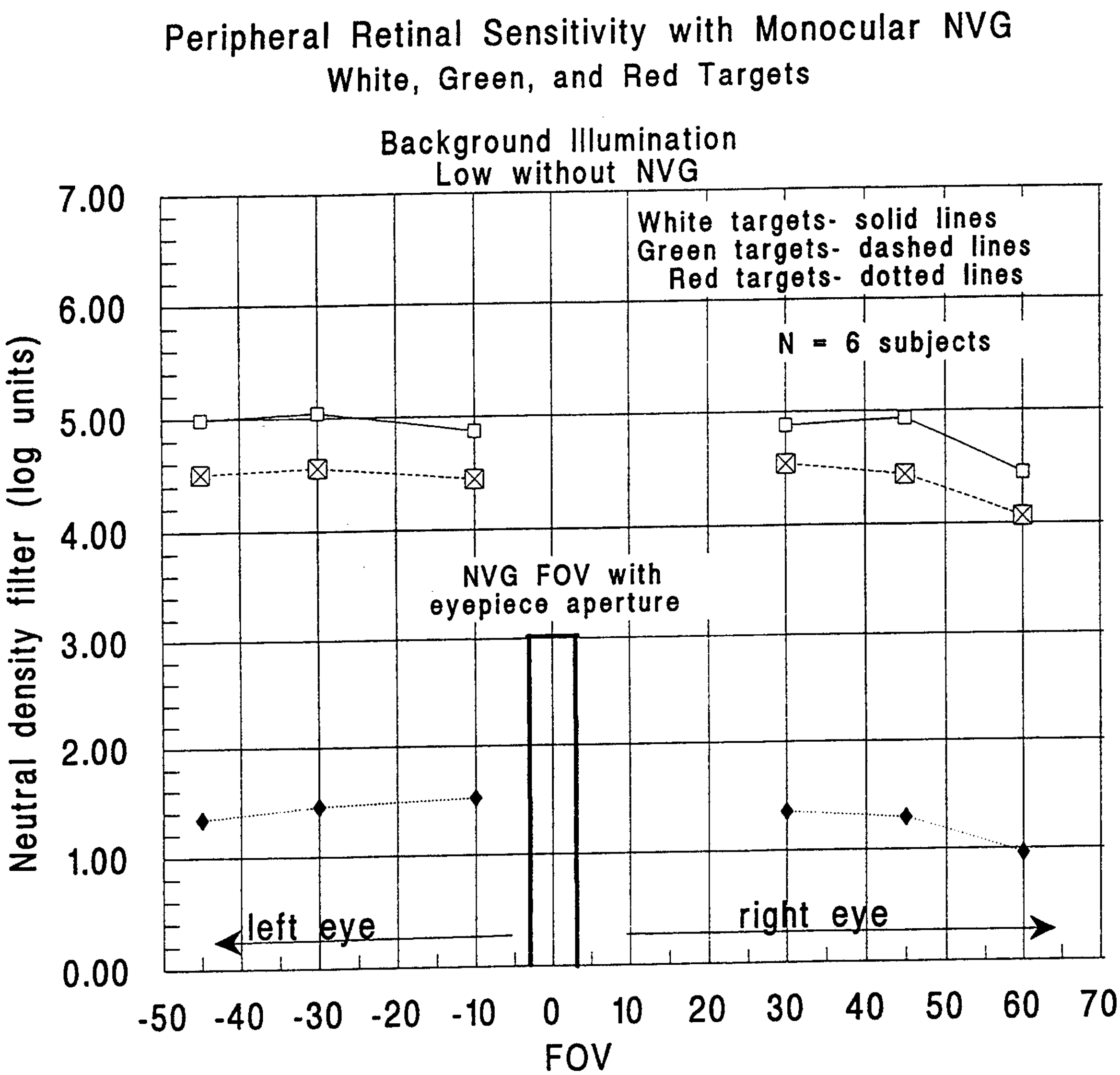

Figure 8. Background effects - illumination low w/o NVG.

Subjective differences between target colors

The average subjective difference of the ND filter values between the white and green targets during this study for all backgrounds and retinal positions (n = 18) was 0.4586 ND, STD = 0.0668; difference between minimum and maximum values = 0.150 ND. The average difference between the white and red targets for all backgrounds and retinal positions (n=18) was 3.232 ND, STD = 0.390; difference between minimum and maximum values = 1.327 ND.

Differences between background light levels

By subtracting the average neutral density filter values for the retinal sensitivity at each retinal location between the background luminance conditions (high, low, and low without display) for each colored target for the mean values of each subject, the average differences for both eyes and each eye are compared in table 3. Significant differences were determined using the 95 percent confidence interval of the mean differences for each eye (N = 18; 6 subjects X 3 positions). Differences between mean values that were **not significant** at the 95% level of certainty are shown with **asterisks** (*) following the values (Chou, Ya-lun, 1975).

Table 3.
Averaged neutral density differences between high, low, and low without display backgrounds.
The display is on the right eye.

Low minus High Background with Display

	Neutral Density (ND) Values	unaided	display side
	Both eyes	left eye	right eye
green	0.904	0.822	0.987
white	0.811	0.727	0.896
red	0.271	0.430	0.111

Low without display minus Low Background with Display

	Neutral Density (ND) Values	unaided	display side
	Both eyes	left eye	right eye
green	0.407	0.052*	0.762
white	0.418	0.116*	0.720
red	0.224	0.036*	0.413

* Differences are **not significant** at 95% level of certainty. The actual measurements of the background luminances of the low without the display and low conditions for the left unaided eye are the same.

Low without display minus High Background with Display

Neutral Density (ND) Values

	Both eyes	unaided left eye	display side right eye
green	1.311	0.874	1.749
white	1.229	0.843	1.616
red	0.495	0.466	0.524

Table 4a.
Differences between display (right) and nondisplay (left) eye
at 30-degree temporal angles .

Left 30-degree minus Right 30-degree Position

Neutral Density (ND) Values

	High background	Low background	Low background without display
green	0.920	0.823	-0.043*
white	0.847	0.673	0.094*
red	-0.004*	0.317	0.047*

* No significant difference at 95% level of certainty.

Table 4b.
Differences between display (right) and nondisplay (left) eye at 45-degree temporal angles .

Left 45-degree minus Right 45-degree Position

Neutral Density (ND) Values

	High background	Low background	Low background without display
green	0.767	0.647	-0.013*
white	0.837	0.670	-0.013*
red	0.047*	0.460	-0.030*

* No significant difference at 95% level of certainty.

Figures 9, 10, and 11 show the ND values for the 30-and 45-degree positions averaged for each eye and the means and standard deviations plotted for each target color at the low, high, and low without display night background illuminations, respectively. For the low background (Figure 9), the differences between the left and right eyes are significant at the 95% level of certainty for all colors ("t" test). For the high background illumination (Figure 10), the difference between the right and left eye sensitivity for the red target is not significant at the 95 percent level of certainty. With the low background without the display (Figure 11), the differences between the right and left eye sensitivities are not significant for all colors.

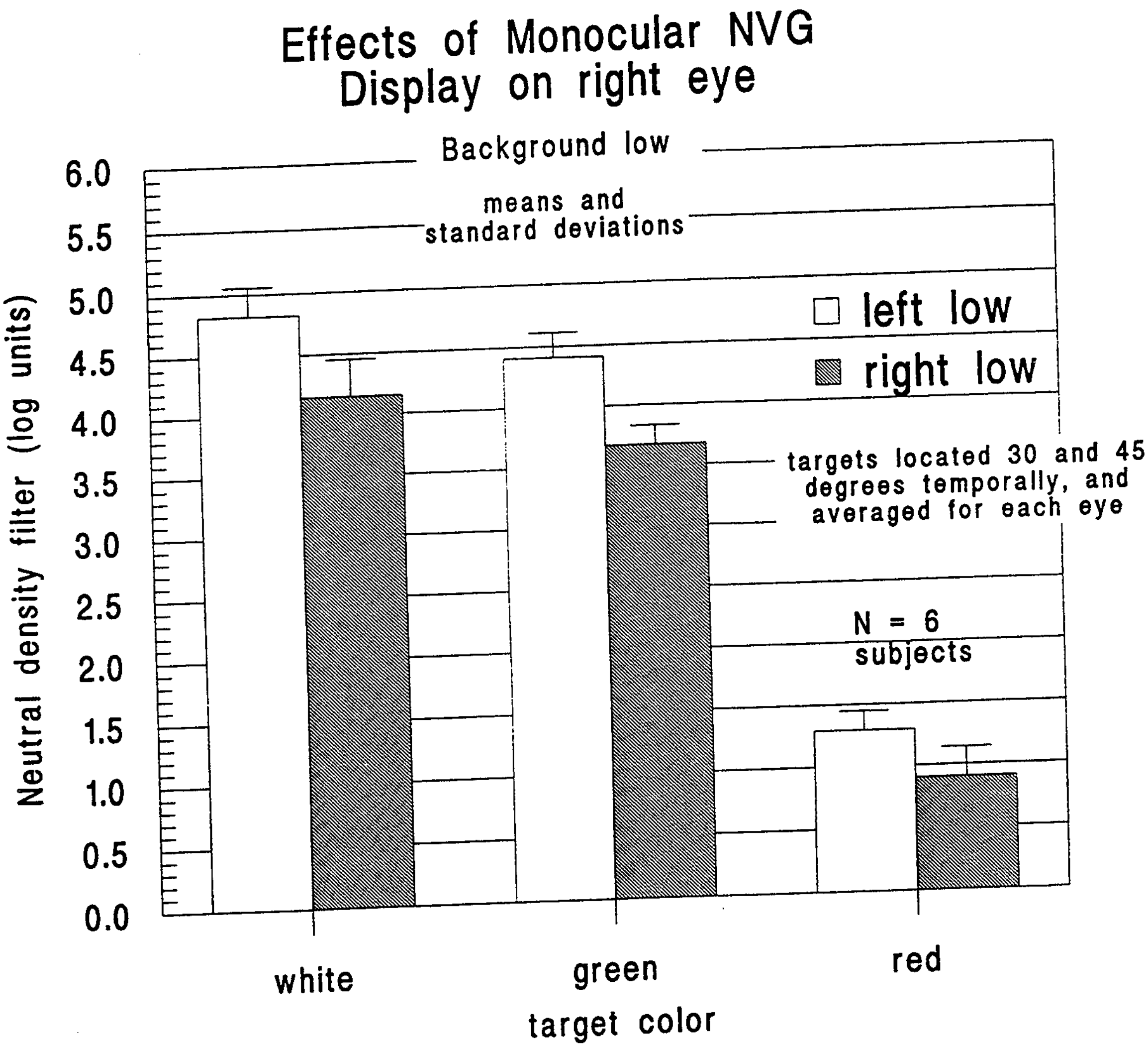

Figure 9. Comparison between right and left eye responses for *low* night background illumination.

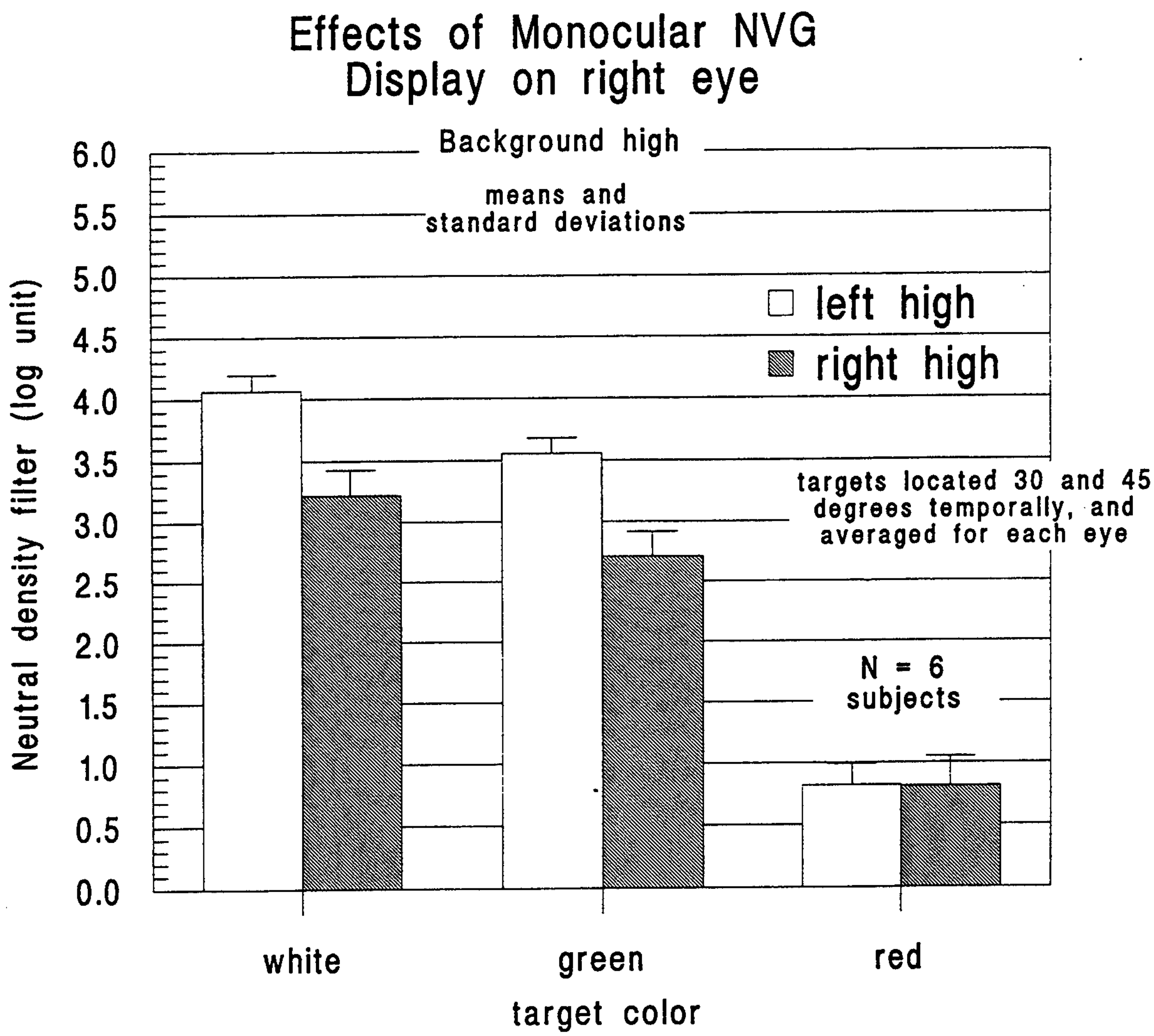

Figure 10. Comparison between right and left eye responses for *high* night background illumination.

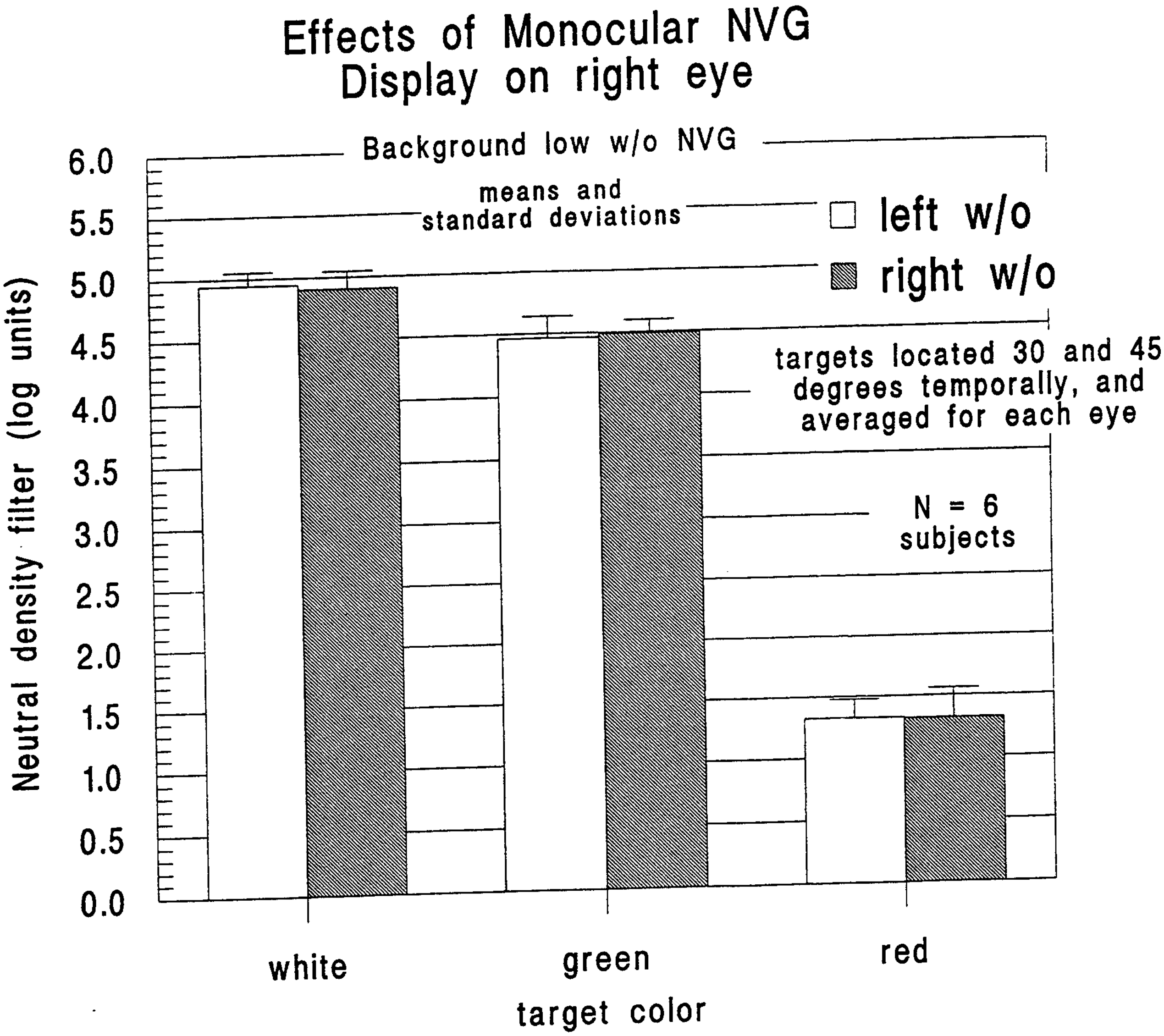

Figure 11. Comparison between right and left eye responses for *low* night background illumination *without display*.

Effects of display on nonviewing eye
at 30-and 45-degree points

Figure 12 shows the effects of the display on the unaided left eye sensitivity with and without the display on the right eye at the low background illumination. The 30- and 45-degree positions were averaged showing the means and standard deviations for each target color. The differences between with and without the display for all target colors were not significant at the 95% level of certainty.

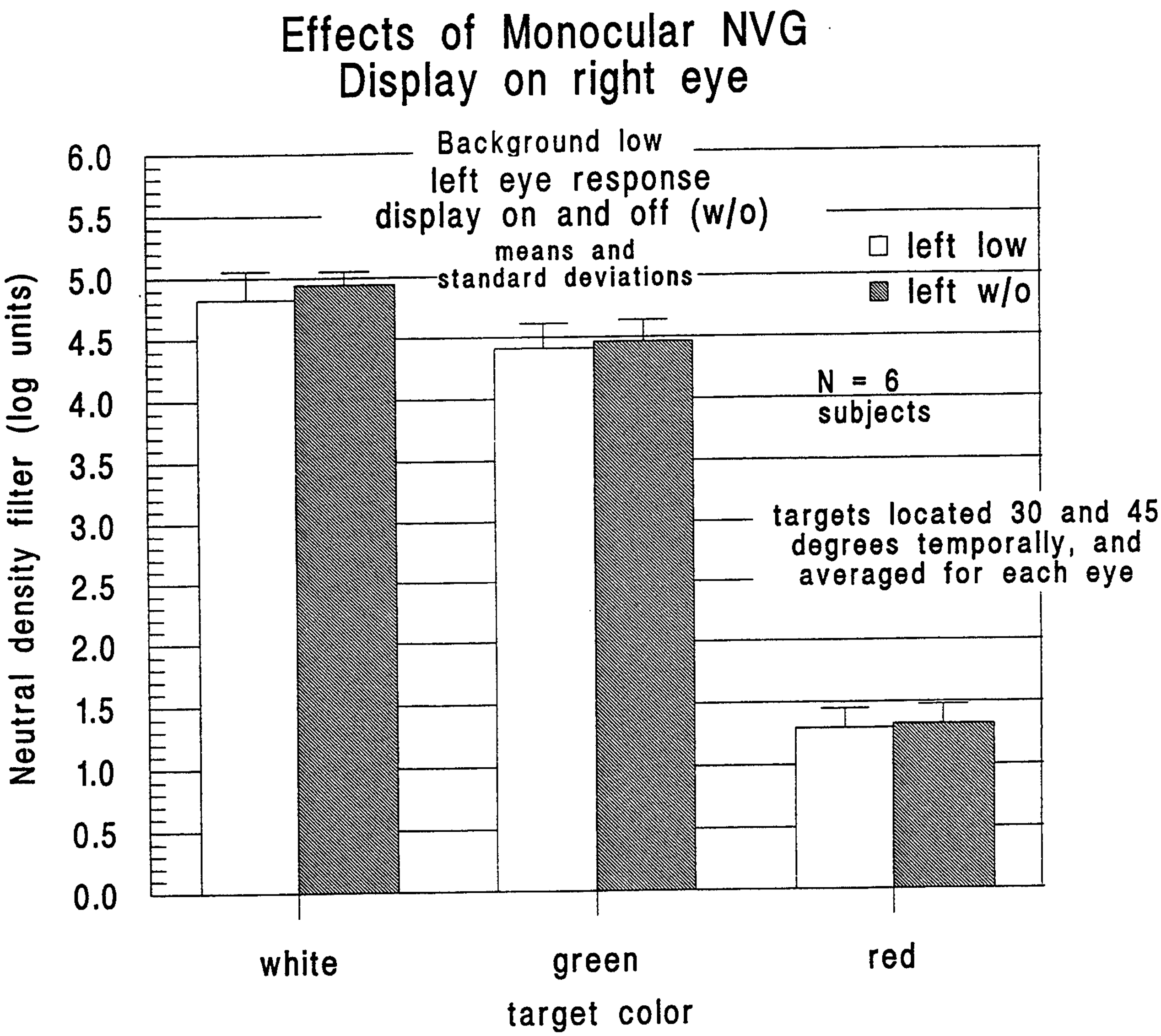

Figure 12. Effects of display on nonviewing eye at 30- and 45-degree points.

Potential edge effects from the ANVIS eyepiece mount

When comparing the differences between the right and left eye responses at the 30-degree peripheral point under the *low background without display* by subtracting the left eye ND values from the right eye values, the differences between the means were not significant (table 4a). At the right and left eye temporal 45-degree points, where edge effects from just the eyepiece mountings were not expected to affect target detection, the differences were also not significant (table 4b). Therefore, the edge effect from the eyepiece mount on reducing target detection was not demonstrated under the test conditions.

Differences in Peripheral Sensitivity within
the display FOV for the unaided eye

At the 10-degree temporal position for the unaided left eye, the targets appeared to be located within the display FOV of the right eye with the low and high background illuminations. With the small aperture on the NVG eyepiece at the low background illumination, the targets appeared outside the reduced FOV of the display. Figure 13 shows the difference in sensitivity at the 10-degree location of the left eye with and without the NVG display. The differences for each color are not significantly different at the 95% level of certainty.

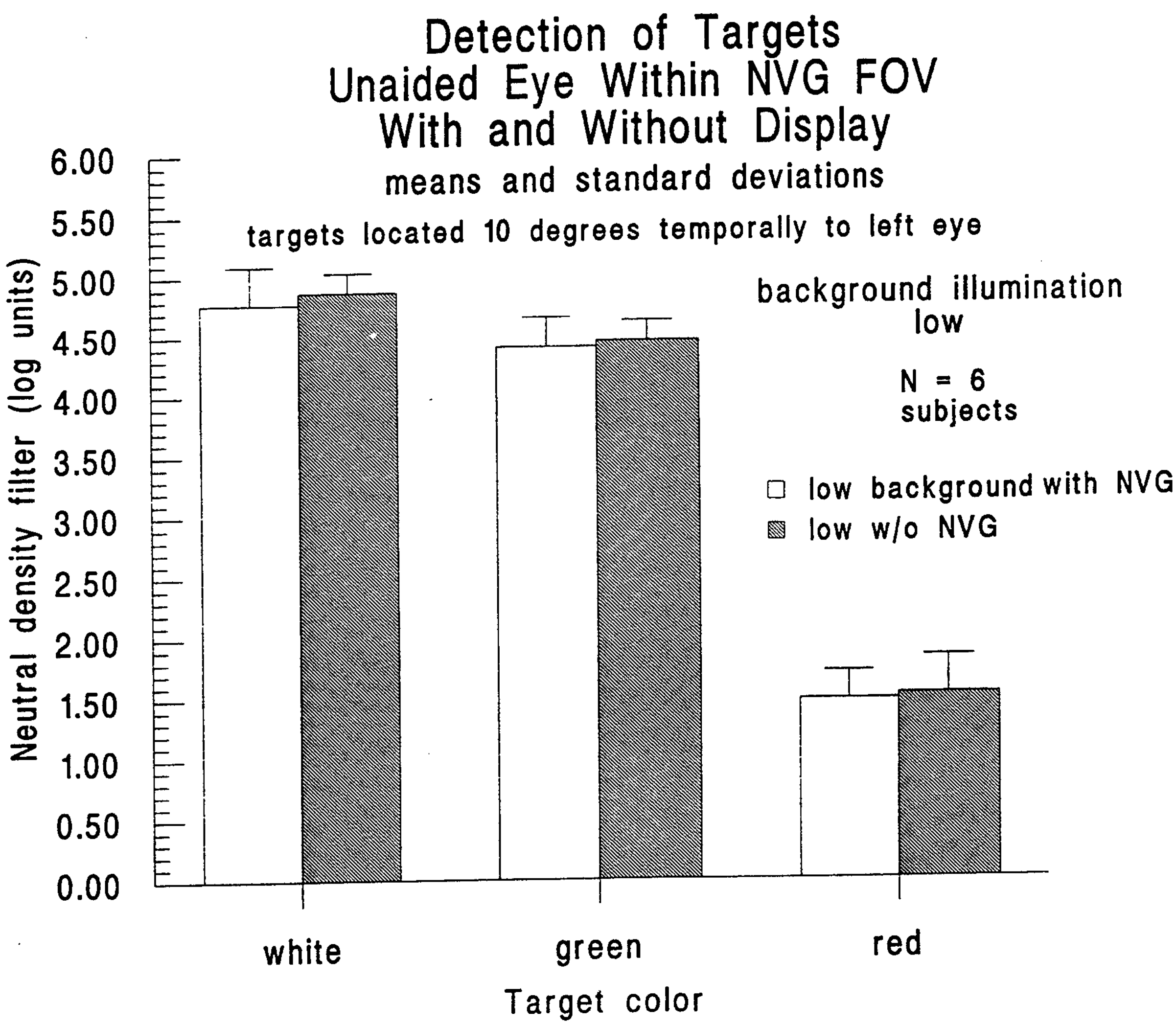

Figure 13. Comparison between left eye response at 10-degree position with and without the display, low night background.

Additional analysis such as the differences among and within subjects, false responses, number of trials comparison between five trials and the median of three trials, and phoria changes between sessions are located in Appendix C (Subject analysis).

Neutral density filter effects on detection range

There were significant effects on peripheral retinal sensitivity on the display eye for each background illumination and target color, except for the red targets under high simulated illumination. The relative decrease in detection ranges at each tested peripheral location can be estimated using a derived binocular eye model of peripheral retinal sensitivity based on Ricco's Law which states that intensity (I) times area (A) is a constant for small angular targets (Davson, 1976).

The differences between the peripheral retina sensitivities with and without the NVG were measured in log ND filters, such that a 1.0 ND filter equates to a reduction of the light intensity of 10 times or 10% transmission of the light. For example, if we found a difference in peripheral retinal sensitivity of 1.0 ND filter at the 30-and 45-degree positions on the display eye, the effect on detection would be the same as wearing a pair of dark sunglasses with 10% transmission.

For this assessment, we would like to know the difference in relative detection ranges at selected peripheral retinal locations with and without the NVG image. Since the expected peripheral targets of concern would be the lights from other aircraft that subtend small angles, the effective stimulus would change as the square of the distance. For example, an object that just fills the size of retinal receptor, will stimulate four retinal receptors when viewed at half the distance, which is the same as increasing the intensity by a factor of 4. Using Rico's Law for small targets (I X A), the relative changes in detection ranges can be calculated by converting the ND filter differences into percent decrease in transmission and then taking the square root of this value.

$$R=[-antilog(\Delta ND)]^{1/2}=antilog(-\Delta ND/2)$$

where R is relative range (normalized)

For convenience, the following conversions from ND filter value to relative range are provided in table 5.

Table 5.
ND value difference to relative range conversion.

ND value	relative range	ND value	relative range
0.0	1.00	**0.7**	0.45
0.1	0.89	**0.8**	0.40
0.2	0.79	**0.9**	0.35
0.3	0.71	**1.0**	0.32
0.4	0.63	**1.2**	0.25
0.5	0.56	**1.4**	0.20
0.6	0.50	**1.6**	0.16

Table 6 shows the calculated relative differences in the detection ranges for the display viewing eye at the 30- and 45- degree temporal peripheral positions for all backgrounds and target colors. The data used for calculations are located in tables 4a and 4b.

Table 6.
Neutral density filter differences and effects on relative detection distances.
Right eye viewing NVG - Left eye unaided for 30- and 45-degree temporal points.

Target Color Background illumination	ND difference LT30-RT30	# Relative Detection Factor	ND difference LT45-RT45	# Relative Detection Factor
Green Low	0.823	**0.39**	0.647	**0.47**
White Low	0.673	**0.46**	0.670	**0.46**
Red Low	0.317	**0.69**	0.460	**0.59**
Green High	0.920	**0.35**	0.767	**0.41**
White High	0.847	**0.38**	0.837	**0.38**
Red High	-0.004*	**1.00**	0.047*	**0.95**
Green Low w/o	-0.043*	**1.05**	-0.013*	**1.02**
White Low w/o	0.094*	**0.90**	-0.013*	**1.02**
Red Low w/o	0.047*	**0.95**	-0.030*	**1.04**

* No significant difference at 0.95 level of certainty

Relative detection factor means that if the green target with the low background illumination could be detected at 1 mile with the unaided left eye at the 30-degree temporal position, the same target could be detected at **0.39** mile for the right eye viewing the monocular ANVIS display at the 30-degree temporal position.

Note the detection ranges of the red targets with the high night background were not affected at the 30- and 45-degree retinal locations by the green display.

The green, white, and red low without (w/o) display conditions are only comparing the differences between the right and left eyes with the display essentially turned off. As expected, there were no significant differences between the right and left eyes without the display.

Table 7 shows the calculated relative differences in detection ranges from the change in simulated night background illumination for the left unaided eye for the green, white, and red targets. The value differences are averaged for all three retinal positions (10-, 30-, and 45-degree points). The data used for the calculations are located in table 3.

Table 7.
Effects of simulated night background illumination
on target detection.

Low minus High Backgrounds for the left unaided eye

Target color	ND difference	Relative detection factor
green	0.822	**0.39**
white	0.727	**0.43**
red	0.430	**0.61**

Note the similar values with a change of background illumination to the values found in table 6 for the effects on detection for the display eye at low background illumination.

Discussion

Differences between the display viewing right and unaided left eye:

The left unaided eye remained dark adapted to the level of the background illumination as shown in table 3. At the 10-degree temporal target position, there was no difference in the detection of targets with or without the display for the left unaided eye for all three target colors at the low background illumination (Figure 13). This finding was a little surprising, since we had anticipated some masking effects to the unaided left eye from the targets that appeared to be located in the FOV of the right display viewing eye. Evidently, for small short duration targets to the unaided eye, masking, suppression and/or retinal rivalry were not demonstrated in this study.

Subjective differences in target colors

It is apparent from tables 3, 4, and 6 that the detection of the red target is very different than the green and white targets with changes in background illumination and between the NVG aided right and the unaided left eye. Changing background illumination showed much less change in the red sensitivity, which is primarily due to Purkinje's shift. As the background illumination decreases, the eye dark adapts and usually becomes proportionally more sensitive, except for targets towards the red end of the visible spectrum. With a red target, decreasing illumination decreases the red sensitivity (photopic to scotopic shift) and increasing illumination increases red sensitivity. Also, the green adapting field from the NVG has less effect on retinal sensitivity for the red targets than the green and white ones.

This minimal effect on red target detection with either the unaided eye or the eye viewing outside the display FOV with changes in night background illumination suggests that aircraft

detection at night outside the NVD FOV should be minimally affected with a monocular viewing device. This is discussed in the next paragraph.

Observations with a single tube ANVIS during NVG flights

The laboratory data show that when using a monocular night imaging display, the unaided eye stays dark adapted to the background level and detection within or outside the display FOV by the unaided eye is not affected by the display for the targets used in this study. This suggests that detecting the lights of aircraft at night could be enhanced with the monocular display from the unrestricted FOV of the unaided eye. To initially explore this assumption, the author wore a single tube ANVIS on the right eye for approximately 10 hours during three different NVG training flights at Fort Rucker, AL, and evaluated whether aircraft were detected initially with the unaided left eye, within the FOV of the right eye, or outside the FOV on the right (display) eye.

Observations were made from two different aircraft and three different locations in the aircraft: (1) the center jump seat behind the pilots in the UH-60, (2) the right and (3) left rear sides in the UH-1 with the rear doors opened. Of the numerous aircraft detected in the high density area of Fort Rucker, only one was detected initially with the unaided left eye before it was detected within the NVG FOV. This occurred while we were taxiing on the airfield and the aircraft had been previously blocked from view by the aircraft structure.

Even at nap of the earth and low level altitudes, at night the red rotating beacons and the position lights on other aircraft can be detected with the NVGs more than 20 miles away, which is much greater than detection in the day time. Therefore, with a periodic scan of the horizon with the NVGs, very few aircraft would be detected with unaided peripheral before being first seen with the NVGs.

In lighted areas, the unaided left eye would see the colors of the lights overlaying the monocular NVG image. With head movement, the lights seen with the unaided eye would tend to separate from the image of the larger lights seen through the single tube NVG. Occasionally, there would be retinal rivalry for several seconds for objects such as the radar altimeter digital display in the cockpit or taxi markings or signs outside the aircraft.

Conclusions

When using a monocular display system, the unaided or nondisplay viewing eye remains dark adapted to the ambient background illumination. Detection of small targets exposed for 1 second was not affected by the output from the display for the nonviewing eye. Surprisingly, targets presented to the unaided eye that appeared to be located within the display field of view from the other NVG viewing eye were detected by the unaided eye the same, with or without the display being activated.

For the display viewing eye, the peripheral retinal sensitivity was reduced for the white and green targets, but much less for the red targets. However, the difference in peripheral retinal sensitivity and the calculated reduction in detection range between the display viewing eye and the unaided eye for the peripheral targets was no greater than the difference in detection between the high and low simulated night backgrounds for the unaided eye. Under high night simulated illumination, there was no significant difference in the detection of the red targets by the unaided left eye or the display viewing eye at equal peripheral viewing angles.

After several observation night flights in a high density aircraft traffic area, using a modified ANVIS with the left channel removed, the author detected only one aircraft with the unaided eye before detection with the monocular image intensifier viewing right eye.

Although the laboratory data from this study suggest that the essentially 70 degrees horizontal FOV for the left unaided eye might increase aircraft detection at night by remaining dark adapted, all but one of the aircraft detections occurred through the NVG image intensifier during the one observer preliminary assessment. The primary cue for detecting aircraft at night with either unaided vision or image intensifiers is the pulsing red or white anti-collision beacons or strobe lights. Since the NVG system light amplification for white light is more than 3000 times and many times more for the red filtered lights, aircraft detection ranges with NVGs greatly exceed the unaided eye. Therefore, with normal scanning of the horizon with the 40-degree NVG FOV, the probability of detecting aircraft with unaided vision before detection using NVGs appears to be very remote.

Possible future USAARL field studies would compare foveal and peripheral visual aircraft detection among day, night unaided, and NVG flights. These studies would be coordinated with the Federal Aviation Agency, U.S. Army Aviation, U.S. Army Safety Center, and the Civil Air Patrol.

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Appendix A.

Briefing to Subjects.

Brief and Instructions to Subjects

To participate in this study you must meet the visual requirements for Class II flight standards.

The purpose of this study is to determine what effects, if any, night vision devices such as ANVIS affect your unaided peripheral vision detection. The military significance of this study may influence future infantry NVG designs and the use of NVGs or the IHADSS for aviation in other than nap of the earth (NOE) and restricted airspace.

The future head up display for the 21st Century Warrior will probably be monocular (over one eye), like "Robo Cop." Although we have some experience with a display for one eye with the Apache helmet display unit (IHADSS), we do not know exactly what information the eye that is not using the display can acquire. Field tests with monocular night imaging devices for infantry soldiers have been inconclusive on the possible benefits of the uncovered nondisplay eye. This study will attempt to quantify peripheral vision detection capability in the eye viewing the display and the other eye that is not viewing the display.

To measure detection with your peripheral vision, we will use a perimeter which looks like a white bowl. Small round dots of different color light can be projected on this bowl at different locations. In front of the right eye, we will mount a single tube ANVIS which will project a green circular image of 40 degrees. We will begin a session by first dark adapting for 30 minutes.

At the beginning of a trial, I will instruct you to look at a central point in the middle of the perimeter just prior to taking a measurement. Between trials, you will be instructed to move your eyes randomly within the NVG field of view as if you were looking for a target. You will hear drum beats at 1-second intervals. During the beginning of one of the drum beats, a small dot will be presented in the perimeter bowl. When you see it, you will tap on the table. You do not have to be able to identify the color or location. To receive credit for seeing the target, you must respond within one second after the target is presented. Wrong responses are scored against you. You will have several practice trials at different peripheral angle locations using different colored targets to familiarize you with the procedures before we record the data.

It will take about 3 hours to obtain all the peripheral vision measurements in the study. We will break this time up into three sessions, which can be completed over several days, if you prefer. The time required for each session will be approximately 30-45 minutes, counting the 30 minutes of dark adaptation time at the beginning of a session.

During a session, if you want to rest your eyes for a few seconds without backing away from the headrest, say so, using the words "not ready." During this timeout period, you can blink and move your eyes around. When you're ready to continue, say "ready" and we will begin the next trial. If you need a longer break of approximately 1-2 minutes to move around and to back-away from the perimeter, say "short break." During this break, do not rub your eyes. We will not turn on any lights so that you retain your dark adaptation. If you need a longer break and have to leave the room, you will need to dark adapt for 30 minutes when you return before resuming the tests.

Prior to beginning the study, we will check your vision using the same equipment as used on your annual flight physicals, but without any eye drops to dilate your eyes. You will not be "grounded" regardless of the visual tests or peripheral measurements in the study.

You will receive no benefits for participating in this study. You may quit at any time without any fear of retribution. Your results will be confidential and not distributed to the other subjects. You will be asked to sign a volunteer consent form before you may participate in this study.

Are there any questions?

Appendix B.

Statistical Data.

Neutral Density Values

Subjects: 6 total; 4 males and 2 females.

Green low	-45	-30	-10	30	45	60
Mean	4.347	4.470	4.397	3.647	3.700	3.410
STD	0.161	0.230	0.186	0.171	0.141	0.181
SEM	0.066	0.094	0.076	0.070	0.057	0.074
95% CI	0.169	0.241	0.195	0.179	0.147	0.190

White low	-45	-30	-10	30	45	60
Mean	4.800	4.843	4.770	4.170	4.130	3.800
STD	0.264	0.203	0.308	0.299	0.311	0.199
SEM	0.108	0.083	0.126	0.122	0.127	0.081
95% CI	0.277	0.213	0.324	0.313	0.326	0.209

Red low	-45	-30	-10	30	45	60
Mean	1.293	1.290	1.483	0.973	0.833	0.547
STD	0.170	0.142	0.192	0.216	0.235	0.104
SEM	0.0700	0.058	0.079	0.088	0.096	0.042
95% CI	0.179	0.149	0.202	0.227	0.246	0.109

Green high	-45	-30	-10	30	45	60
Mean	3.503	3.607	3.637	2.687	2.737	2.373
STD	0.109	0.127	0.145	0.282	0.074	0.302
SEM	0.044	0.052	0.059	0.115	0.030	0.123
95% CI	0.114	0.133	0.152	0.296	0.078	0.316

White high	-45	-30	-10	30	45	60
Mean	4.050	4.080	4.103	3.233	3.213	2.967
STD	0.111	0.144	0.153	0.271	0.097	0.251
SEM	0.045	0.059	0.062	0.110	0.040	0.102
95% CI	0.117	0.151	0.160	0.285	0.102	0.263

Red high	-45	-30	-10	30	45	60
Mean	0.767	0.873	1.137	0.877	0.720	0.423
STD	0.191	0.128	0.191	0.195	0.262	0.207
SEM	0.078	0.052	0.078	0.080	0.107	0.085
95% CI	0.200	0.135	0.201	0.204	0.275	0.218

STD = standard deviation; SEM = standard error of the mean;
95% CI = the 95 percent confidence interval of the mean.
For 95% CI, 10 degrees of freedom, two tail, t=2.571

Statistics Cont.

Green low w/o	-45	-30	-10	30	45	60
Mean	4.427	4.497	4.447	4.540	4.440	4.063
STD	0.086	0.231	0.125	0.105	0.083	0.186
SEM	0.035	0.094	0.051	0.043	0.034	0.076
95% CI	0.090	0.242	0.131	0.110	0.087	0.195

White low w/o	-45	-30	-10	30	45	60
Mean	4.913	4.977	4.870	4.883	4.927	4.450
STD	0.047	0.141	0.106	0.126	0.159	0.164
SEM	0.019	0.058	0.043	0.051	0.065	0.067
95% CI	0.050	0.148	0.111	0.132	0.167	0.172

Red low w/o	-45	-30	-10	30	45	60
Mean	1.257	1.393	1.523	1.347	1.287	0.960
STD	0.128	0.155	0.292	0.220	0.260	0.083
SEM	0.052	0.063	0.119	0.090	0.106	0.034
95% CI	0.134	0.163	0.306	0.231	0.273	0.087

Differences between Background Illumination at each retinal location (ND filter)

Low minus High Background

Target color	Left eye (unaided) -45	-30	-10	Right eye (display) 30	45	60
green	0.843	0.863	0.760	0.960	0.963	1.037
white	0.750	0.763	0.667	0.937	0.917	0.833
red	0.527	0.417	0.347	0.070	0.113	0.123

Average differences: Low minus High

Eye	Green	White	Red
right and left	0.904	0.811	0.266
left	0.822	0.727	0.430
right	0.987	0.896	0.102

Low without display minus low background

Target color	Left eye (unaided) -45	-30	-10	Right eye (display) 30	45	60
green	0.080	0.027	0.050	0.893	0.740	0.653
white	0.113	0.134	0.100	0.713	0.797	0.650
red	-0.037	0.103	0.040	0.373	0.453	0.413

Average differences: Low w/o display minus Low

Eye	Green	White	Red
right and left	0.407	0.418	0.224
left	0.052	0.116	0.036
right	0.762	0.720	0.413

Differences between target colors at each retinal location for a given background illumination (ND filters)

white minus green

Color and background	Left eye (unaided) -45	-30	-10	Right eye (display) 30	45	60
white low - green low	0.453	0.373	0.373	0.523	0.430	0.390
white w/o - green w/o	0.487	0.480	0.423	0.343	0.487	0.387
white high - green high	0.547	0.474	0.467	0.547	0.477	0.593

Average differences: white minus green

Eye	Low	With out NVG	High
right and left	0.424	0.435	0.518
left	0.400	0.463	0.496
right	0.448	0.406	0.539

	white minus red					
	Left eye (unaided)			Right eye (display)		
Color and background	-45	-30	-10	30	45	60
white low - red low	3.507	3.553	3.287	3.287	3.197	3.297
white low w/o - red low w/o	3.657	3.584	3.347	3.537	3.640	3.490
white high - red high	3.283	3.207	2.967	2.330	2.493	2.543

Average differences: white minus red

Eye	Low	Without NVG	High
right and left	3.354	3.543	2.803
left	3.449	3.529	3.152
right	3.260	3.556	2.455

Appendix C.

Subject Analysis.

Differences among subjects

Figures C1 through C3 show mean retinal sensitivity (three locations) for each subject for each eye and target color at a given background luminance. Targets are located at 10, 30, and 45 degrees temporally for the left eye without the display and at 30, 45, and 60 degrees for the right display viewing eye. Therefore, the average neutral density values are different between the right and left eyes for the low without display condition (Figure C3).

Subjects are labeled A through F arbitrarily. For a given condition, there were noticeable small differences among subjects, although these differences were not evaluated statistically. After ranking the subjects for each condition from 1 (highest sensitivity) to 6 (lowest sensitivity) with a mid rating of 3.5, subject "A" consistently showed the most peripheral retinal sensitivity for all target colors, backgrounds, and viewing eye, with an average ranking score of 1.44. Subject "A" was ranked number 1 for 14 of the 18 conditions. The calculated probability of obtaining 14 out of 18 number one rankings with each a single probability of occurrence of 1 in 6 is 0.00000002. Subject "A" was also the youngest of the subjects.

Subject "B" showed the lowest averaged peripheral retinal sensitivity with a mean ranking of 5.19 for all the conditions, obtaining the ranking score of 6 (lowest) for 7 out of 18 conditions. The calculated probability of obtaining 7 out of 18 rankings of the lowest value is 0.0015. Subject "B" was the next to the oldest subject. For the remaining 4 subjects, the average rankings over all conditions ranged from 3.36 to 3.97.

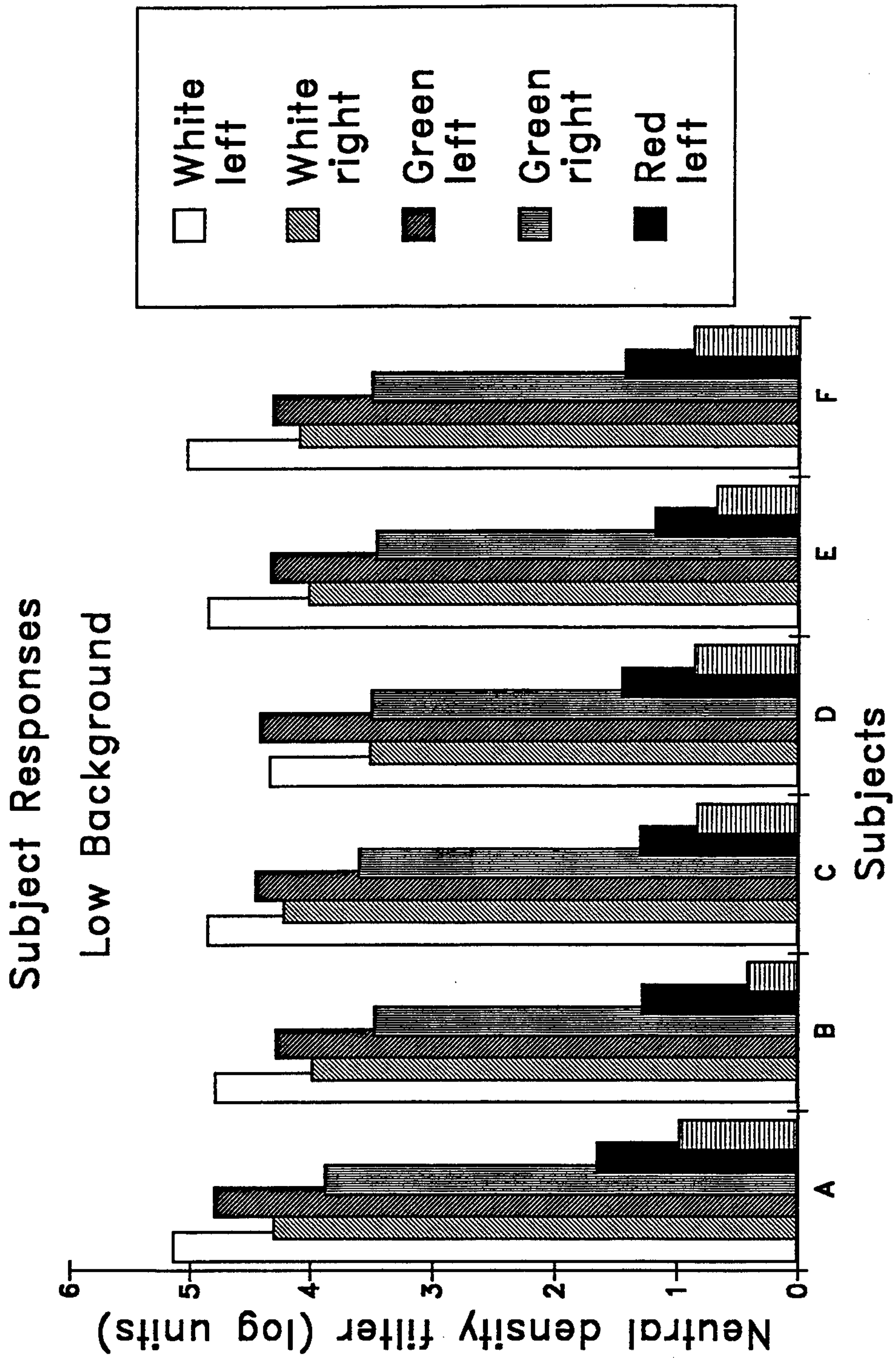

Figure C1. Differences among subjects - low background illumination.

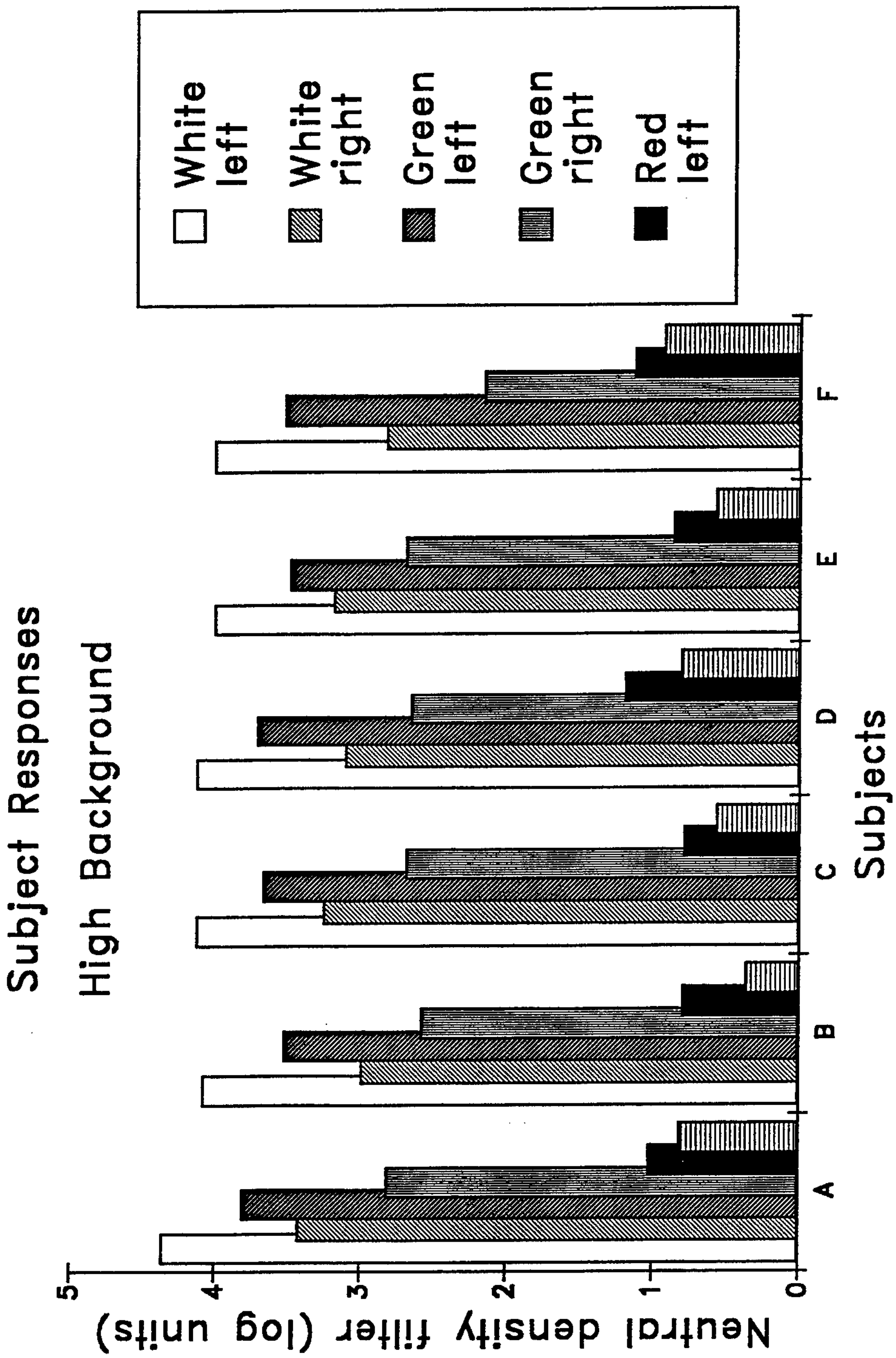

Figure C2. Differences among subjects - high background illumination.

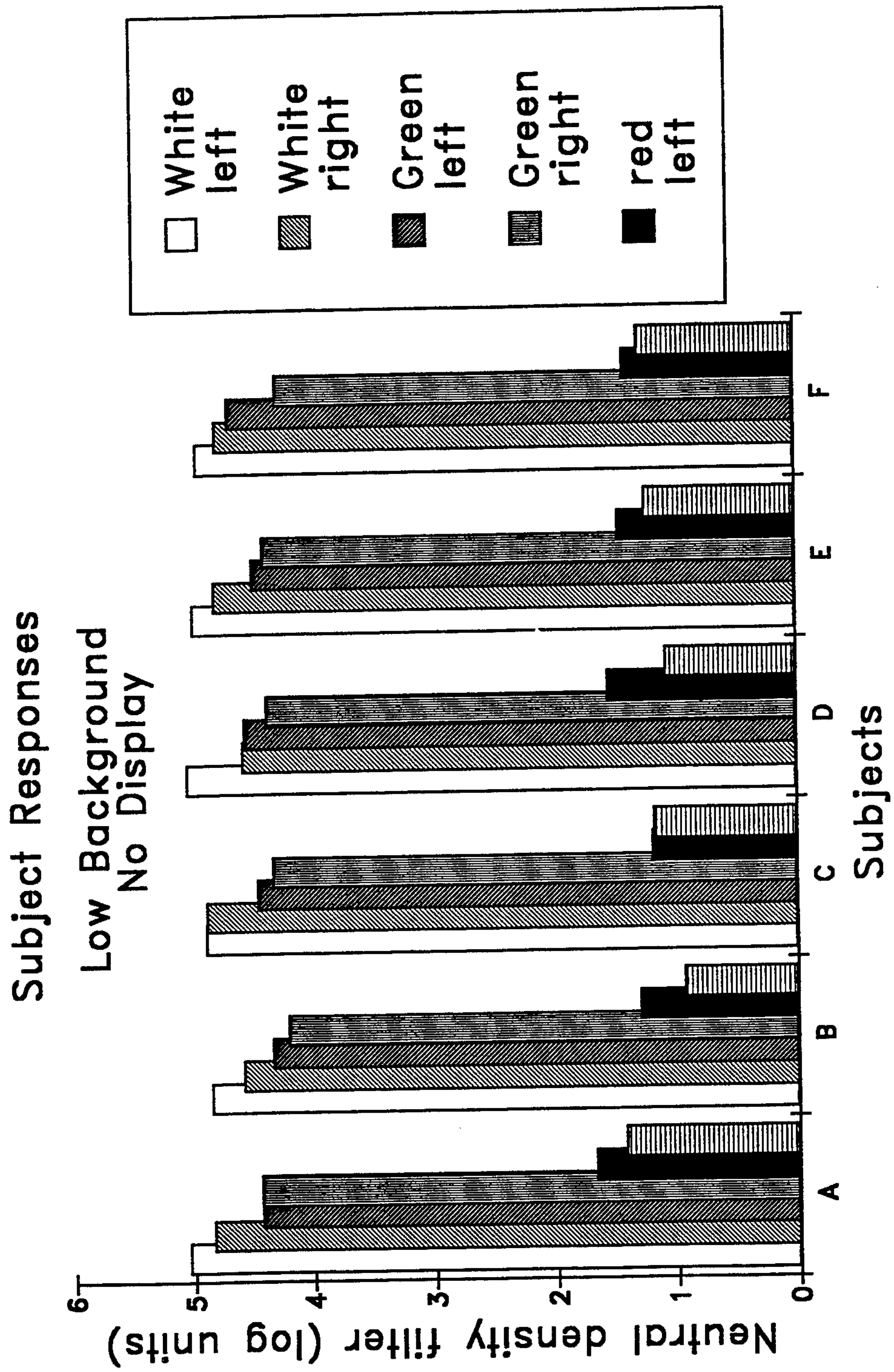

Figure C3. Differences among subjects - low background illumination without display.

Differences within subjects

Figure C4 shows the distribution of the range of ND values for the five trials used for each subject, target location, background, and target color (n = 324). With the smallest interval between ND filters of 0.10, the mean range between the highest and lowest value for five trials was 0.23 ND, with a standard deviation of 0.13.

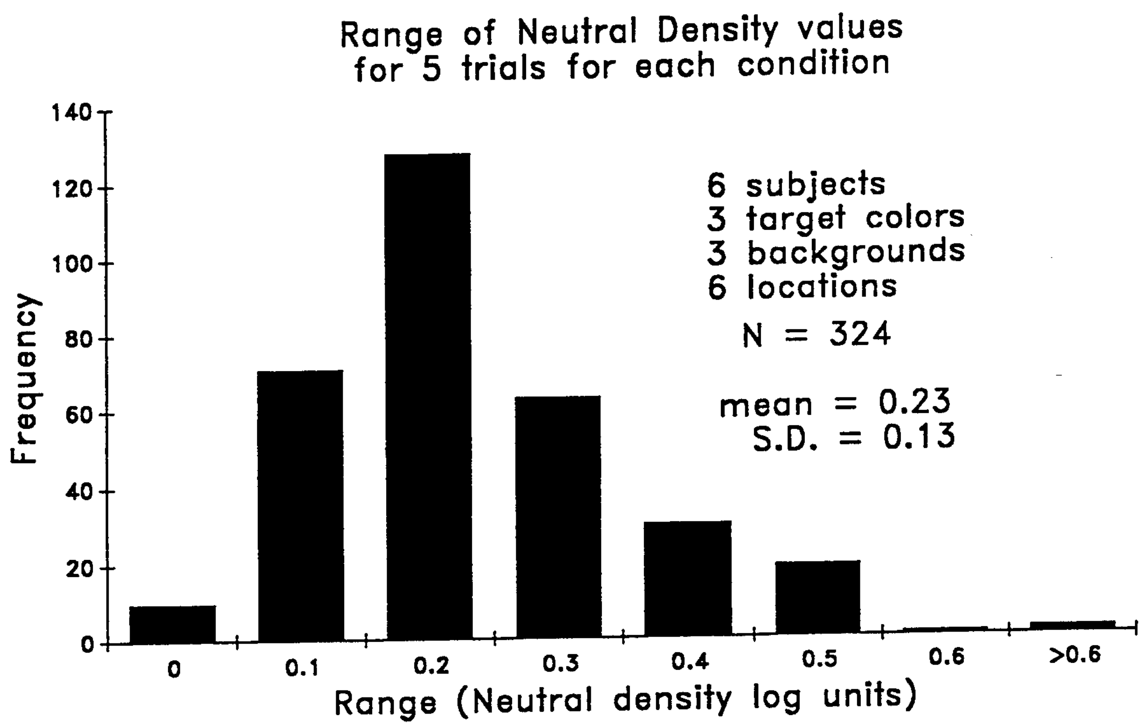

Figure C4. ND distribution range for five trials for all conditions.

False responses

Only false positive responses were recorded. False positive responses are those where there is no target and subjects report seeing something. Since all stimuli began below threshold, there were no false negative stimuli where the targets were above their previously found threshold and the subjects failed to respond. Subject "A" had 21 false positive responses out of 270 trials plus 21 false (93% correct response), but also had the highest overall sensitivity. Four of the subjects had zero false positives and the remaining subject had two false responses. The subjects were aware that false responses would increase the time for each session and therefore the subjective thresholds for five of the six subjects were 99 % or greater probability of certainty.

Difference between using the mean of five trials or the median of the first three trials, or the value of the first trial for a given set

Figure C5 shows a frequency distribution of the absolute differences between the mean value of five trials and the median of the first three trials.

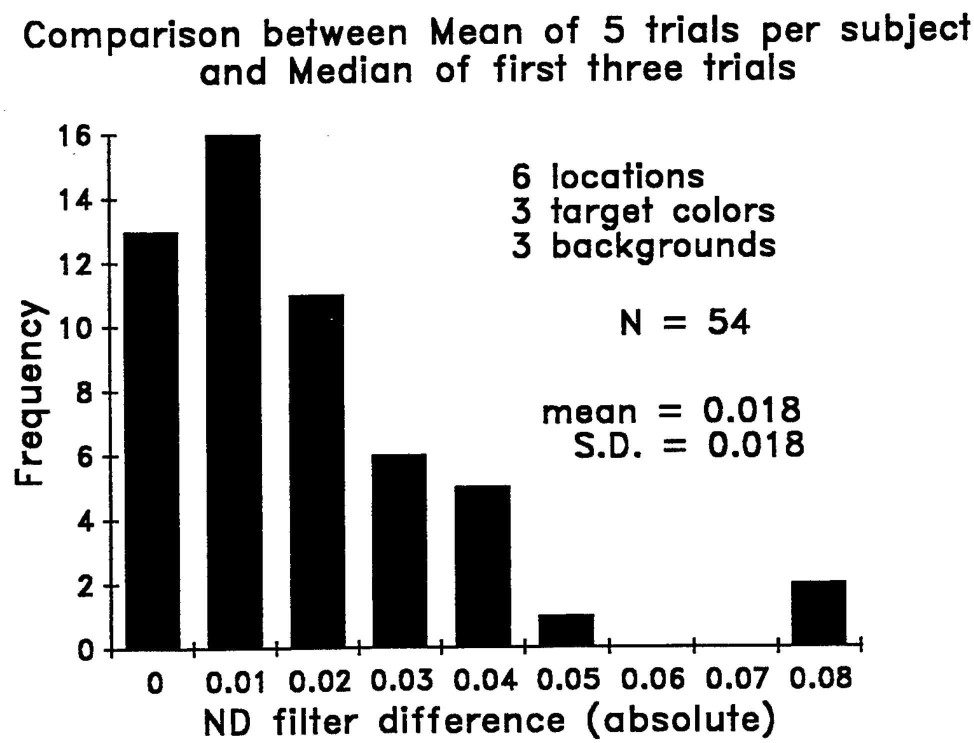

Figure C5. Comparison between the mean of five trials and the median of the first three trials.

Figure C6 shows a frequency distribution of the absolute differences between the mean value of five trials and the value of the first trial. Note the greater range of differences when using only the first value versus the median of the first three measurements.

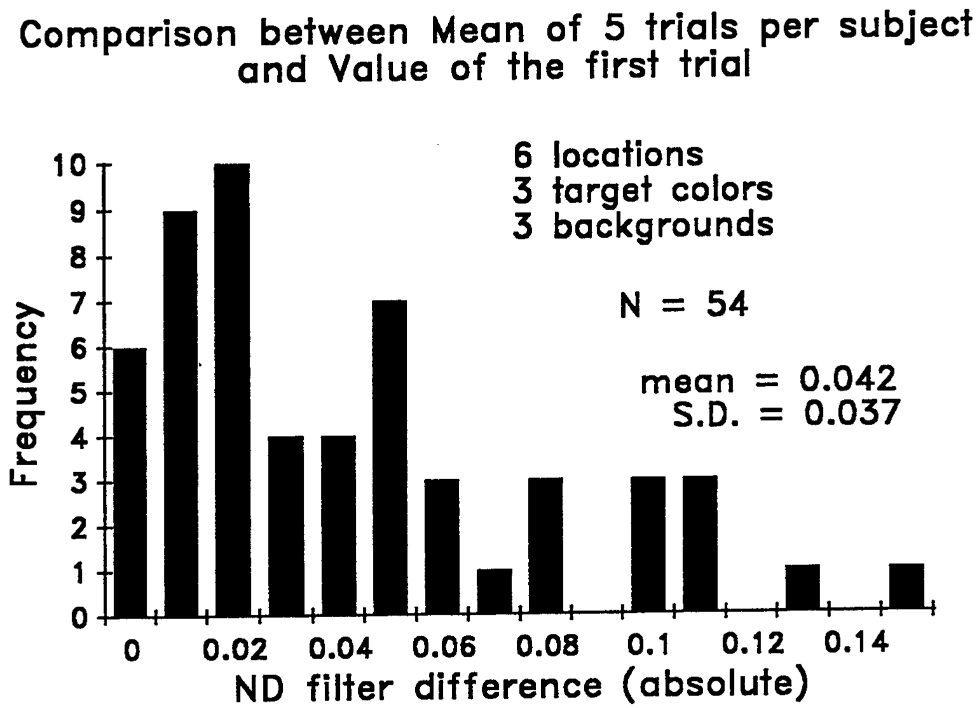

Figure C6. Comparison between the mean of five trials andthe value of the first trial.

Changes in phoria for light levels and before and after a session

The maximum relative difference between phorias before and after a set (one background and one color) was 2 degrees (3.5 prism diopters) for any of the subjects. The phorias stayed fairly constant for all backgrounds for four of the subjects, with a slight increase in convergence or esophoria with the lower display background conditions. When the lens cap with the small aperture was placed on the eyepiece for the low without display background (< 5 degrees FOV for display), subject "F"'s phorias were 4 to 5 degrees more convergent (7 - 9 prism diopters) than when the full FOV was displayed for the low and high background conditions. Subject "A" showed 3 and 4 degrees (5 & 7 prism diopters) more convergence for the low and low w/o display background than the high background. This increase in convergence with decreased background illumination could be due to the subjects unintentionally focusing on the small targets at 300 millimeters (3.33 diopters) instead of the arrow marker as seen through the intensifier tube at 0.50 diopters, or the subjects focusing towards their dark focus point.